PHOTOGRAPHIC OPTICS.

PHOTOGRAPHIC OPTICS;

INCLUDING THE DESCRIPTION OF

LENSES AND ENLARGING APPARATUS.

Désiré

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WITH FIVE PLATES AND EIGHTY-SEVEN WOODCUTS.

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PREFACE.

To show clearly the principles on which the optical instruments used by photographers are constructed is the object of this little volume. Treatises on physics—nay more, treatises exclusively on optics—are silent about these instruments, and about terms—such as *chemical focus*, *depth of focus*, *distortion*, &c.—which are in daily use among photographers. This is because modern optics has been hitherto confined to the study of telescopic and microscopic lenses, which never, like photographic lenses, receive pencils very oblique to their principal axis. The consequence is, that the aberrations which must be destroyed in these objectives, namely, *spherical aberration* and *chromatic aberration*, have alone been studied. At most, the other aberrations,—namely, *distortion*, *curvature of the field*, and *astigmation*,—have been made by a few authors, such as Airy and Gauss, who have studied them in connexion with *eye-pieces*, the subject of some rare memoirs, of which, moreover, no mention is made in any work on physics or optics.

This volume is divided into two books; the first (and this is the principal one) the optics of photographic objectives, the second that of enlarging apparatus.

The first book is divided into chapters in which we describe the principles of general optics. We dwell particularly on points imperfectly known, or directly related to photography,—such as the chemical action of light; the images produced by small apertures; the absorption of light by

transparent media; the reflecting power of mirrors; the position of maximum chemical action in the spectrum on substances sensitive to light; photographic achromatism; the manufacture of lenses; the law of conjugate foci, and the size of images at the foci of lenses; the determination ofthe absolute focus of simple lenses and of optical combinations of several lenses, &c.

The five aberrations of most interest have been the object of our especial care.

A radiating point (of homogeneous colour) being placed at infinity, and in the axis of a convergent lens, emits parallel rays, which on emerging from the lens do not meet at one point in the axis; and therefore the image of the point is surrounded by a circle of diffused light, called the *circle of spherical aberration.* If the point is placed some degrees out of the axis, the circle of aberration becomes elliptical; and if the point is very obliquely placed, its image takes the form of a comet. We have carefully examined the conditions necessary to reduce this spherical aberration to the minimum by the employment of the diaphragm, or better by joining to the convergent lens a divergent lens, with appropriate radii of curvature, which makes the combination *aplanatic*, that is, free from spherical aberration along its axis.

If the radiating point is not of homogeneous colour—if, for instance, it is white—for one ray incident on the lens there are several refracted rays of different colours which cut the axis at different points,—a phenomenon which has received the name of *chromatic aberration*, and which is corrected by joining to the convergent lens a divergent lens formed of another kind of glass, and with suitable radii of curvature. But a lens *achromatic* for incident rays parallel to its axis, cannot be so for rays oblique to this axis; and the optician has therefore to solve the problem of reducing the chromatic

aberration to the minimum for the latter while annulling it for the former, a problem which we shall examine in detail.

If instead of a radiating point placed at infinity, we take, for example, *a plane* situated at infinity, and if we reduce the lens to its optical centre, we shall find that the image, at the focus of the lens, cannot be received on a plane surface—a *curved surface* being necessary to receive it: this is the *aberration of form*, or the *curvature of the field.* Further, the two meridians of the lens have, for pencils oblique to its axis, different focal lengths, and thence *two* different *fields of curvature*—an aberration which has received the name of astigmation.

Lastly, another aberration results from the thickness of the lens, and from the position of the diaphragm, the effect of which is to render the straight lines of the object to be reproduced curved in the image,—an aberration which has received the name of *distortion.*

All these aberrations are called *positive* when they are applied to single convergent lenses, and *negative* to single divergent lenses. All are corrected in an optical combination of divergent and convergent lenses (which in practice is always convergent); but the corrections may be excessive or insufficient, and then the aberrations may be, in a convergent optical combination, either positive or negative.

The study of aberrations is followed by that of photographic lenses, which we divide into two classes,—*aplanatic objectives*, which give sharp images over a small field with their entire aperture; and *non-aplanatic objectives*, which give sharp images only on the condition of being limited by a diaphragm to a very small fraction of their aperture, but which generally include a large angle, and consequently give a sharp image over a large field.

Many new non-aplanatic objectives have been produced in late years, but we positively condemn their introduction

among photographers, and regard them, not as a step in advance, but the reverse, and for the following reasons:—

The practice of photography has established that, when the image at the focus of a lens is wanting in intensity, the photographic reproduction of this image is itself wanting in relief, the foregrounds being too black, the objects situated in the horizon confounded with the sky, and the clouds in the sky replaced by a plain ground of uniform tint: the proof, in a word, is wanting in aërial perspective, and, if it be a portrait, in vigour and relief. For, to give *sharp* images non-aplanatic objectives require very small diaphragms, and generally of from $\frac{f}{40}$ to $\frac{f}{72}$, f being their focal length: hence an insufficient intensity in the image and the defect which we have just pointed out. But, exempt from distortion, and including a considerable angle, they are useful in some special cases, such as the reproduction of *cartes*, buildings situated a very short distance, or landscapes and buildings strongly illuminated by a powerful sun.

Aplanatic objectives, under the head of which rank the *triplet*, include a less angle, but do not require diaphragms exceeding $\frac{f}{30}$; and therefore they give more artistic photographic proofs, in which the foregrounds and the horizons are well brought out, and the skies have clouds. If the light is insufficient, they are employed with a larger diaphragm; and the sharpness of the image is not destroyed as with non-aplanatic objectives, but only limited to a smaller field. They can be used for portraits in the open air, groups, and animated scenes, with their entire aperture,—an advantage which is invaluable in practice. Lastly, the angle they include, being between 50 and 60 degrees, is more than sufficient, because if this angle is more considerable the effect of the perspective is doubtless more astonishing than agreeable.

In our opinion, therefore, the use of non-aplanatic objectives —such as the *single lens*, the *globe lens*, *Mr. Ross's doublet*, and that of *M. de Steinheil*—should be abandoned (except in some special cases which we have enumerated above) for that of aplanatic objectives among which the *triplet* is the best, as being free from distortion.

For portraits the only possible lens is *Petzval's doublet*, but we are able to state that this form itself will soon be abandoned for a combination recently invented by M. de Steinheil of Munich, which is free from spherical and chromatic aberrations both along its axis and obliquely to it, from distortion and from astigmation, and which, further, reduces the curvature of the field to a much smaller quantity.* This lens, the fruit of immense and ingenious calculations, will not fail to attract the attention of all photographers, as in every respect it deserves to do.

It is not enough to be in possession of good objectives, it is necessary to know how to use them,—a thing about which ninety-nine photographers out of a hundred are in ignorance. To use a lens improperly is to produce portraits false in perspective, buildings and houses falling into the street, &c. We point out, in a special chapter, how an objective should be employed and under what circumstances.

The second book of this work treats of enlargements. In it we examine the history of enlarging apparatus, the theory of them, their setting-up, their management, and the application to them of the heliostat and of artificial light.

We therein clearly establish the principle that the origin of the want of sharpness in the images produced by most enlarging apparatus is due to the circle of aberration of the

* The author of this work is in possession of one of these new objectives through the courtesy of M. de Steinheil. These objectives are not as yet on sale.

condensers which illuminate the negative to be enlarged, the effect of this being to cause diffraction-blurrings or multiple lines in all the sharply defined outlines of the enlarged image. By destroying this circle of aberration, either by the employment of condensers of small diameter, or of aplanatic condensers, the production of these diffraction-blurrings is prevented, and the enlarged images then become admirably sharp.

Such are the principal contents of this little volume, which is not, indeed, to be considered as more than the summary of a more complete work; but which, we hope, will be of some use to the amateur, the professional photographer, the physicist, the optician, and all others interested in the progress of modern optics.

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THE

PRACTICAL OPTICS

OF

PHOTOGRAPHY.

BOOK I.

PHOTOGRAPHIC OBJECTIVES.

CHAPTER I.

PRELIMINARY IDEAS.

Light.—Optics.—When we place our hand near a stove, we experience a peculiar sensation which we call *heat;* when our ear perceives a sensation, we say it is produced by a *sound* or noise; so in like manner, if we distinguish the colour and outline of an object, it is because this object sends us *light*, for in *darkness* we do not even recognise its presence. *By day* we easily see all objects which chance or our will throws in our way, because they all reflect light; but *at night* we lose sight of them. From this it evidently follows that they do not shine by their own light, but that they borrow their light from a source, which everybody knows is the sun. In fact, some hours before the rising of this body we begin to discern objects indistinctly, and the nearer we approach the hour of its rising the more we distinguish with clearness everything about us; at length, when his brilliant disc appears above the horizon, light floods with the fullest intensity all parts of the space which surrounds us. It seems, therefore,

that there exists, necessarily, between the sun and ourselves some mode of communication of which our eyes are the intermedium; it is this mode of communication which constitutes what is called *light.*

But, inasmuch as, according to what we have just said, objects at the surface of our globe cease to be visible with the disappearance of the sun below the horizon, *light* which shows them to us so varied in aspect must, to do so, be also susceptible of various modifications. Now, the sun is white, and yet the trees appear green, the sky blue, and buildings of a hundred other tints. Is it not evident, then, that if the white light of the sun did not contain all these colours we should not perceive them? The study of all phenomena relating to light is called "*optics.*"

The Sources of Light; their Intensity.—The sun shines with a splendour peculiar to itself; terrestrial objects with a borrowed brightness. It is not meant by this that there are not on the surface of the earth self-luminous bodies, for that would be very erroneous, as material bodies become luminous when their temperature is sufficiently raised; thus the jets of gas which at night light the streets of our large towns shine by their own light (for they are visible by day as well as by night), and continue to do so as long as the cause which produces them continues to act. Artificial lights are, besides, capable of producing photographic images as well as the light of the sun, or objects illuminated by it; but at all times, their intensity being relatively very feeble, their action on sensitive substances is very slow.

Among the sources of artificial light, of which photographers make use when sunlight or daylight fails them (as for example when reproducing the interiors of grottoes, the crypts of a church, &c.), we shall mention, in the first place, the flame obtained by the combustion of a wire of *magnesium.* This flame is of considerable brightness, and, moreover, emits a very large number of chemical rays, of which we shall presently speak.

A stick of compact magnesia (obtained by the calcination of the nitrate of magnesia) substituted for the stick of chalk in the Drummond light emits a very vivid light also, and one quite comparable to that given out by magnesium in combustion.

The electric light, though of exceeding brightness, exerts but little action on photographic surfaces. But the light obtained by the mercury-lamp of Way, though not so bright as that obtained between the charcoal points of the ordinary electric lamp, is much more intense in relation to such surfaces.

Chemical action of Light.—When a very young plant is placed in a cellar, it is observed that as it becomes developed all its shoots are directed not towards the openings by which the air enters, but towards those which admit the light. Moreover, the leaves of the plant in place of being green, like those of our garden-plants, are white or slightly yellowish. But if it be exposed to the sun, its leaves at the end of a few hours will have become green under the influence of solar light.

Chloride of gold dissolved in ether and exposed to the solar rays slowly decomposes and deposits metallic gold.

White *chloride of silver* blackens in the light by losing chlorine.

These, therefore, are examples of the chemical action of light. This action, however, is not due to any elevation of temperature; for when, for instance, the chloride of silver is placed in a liquid in which a thermometer is plunged, no change of temperature is observed: besides, the chloride remains white when it is heated in darkness. Light, therefore, induces a true chemical action. The list of substances sensitive to light is extremely long; and it is even supposed, with some show of truth, that there probably does not exist a single substance in nature which is not affected by light. Although the chemical properties are often changed, the alteration is not always apparent. It is thus with *mercuric nitrate* when submitted to light, which does not visibly appear to change its properties; but the action of the light is revealed

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by chemical reagents of proto-salts of mercury, which form an image wherever the light has acted. The same thing may be said of the bitumen of Judæa, which is so changed by light as to lose its solubility in its ordinary solvents.

Among the bodies which are rapidly decomposed when exposed to the solar rays we may mention the salts of gold, silver, mercury, chromium, uranium, and a great number of organic substances. The *salts of silver* are nearly all decomposed, more or less rapidly, when exposed to the solar rays. Nearly all these salts are white, but there are also some which are red, yellow, or green; which exceptional colours, however, do not preserve them from decomposition.

What is more curious is, that it is not the *illuminating part* of light which acts chemically in the examples we have just given. For a clear yellow glass, which allows *illuminating light* to pass very readily, altogether stops *chemical light*, or that light which decomposes chloride of gold and chloride of silver; and on the contrary, a very deep violet glass, through which we can see with difficulty, hardly intercepts the chemical rays at all. So that chloride of silver blackens almost as quickly under a violet glass as under a clear one, and not at all behind a yellow glass.

Movement of Light in straight lines.—Light moves in a straight line; hence we cease to perceive an object when any obstacle is placed between the object and our eye.

A luminous point, *a* (fig. 1), emits *luminous rays, a b, a c, a d,* in all directions. A *pencil, c a b,* is composed of several rays, *a b, a c,* proceeding from a luminous point *a*, and forming with each other a *very small* angle, *c a b.*

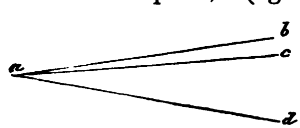


Fig. 1.

A *bundle, b a d,* is composed of several pencils.

We usually treat of the straight lines a b, a c, which include a pencil, b a c, as if they were parallel. To allow for this supposition, the angle b a c ought to be very small: less than half a degree, for instance.

Every point of an illuminated object sends out rays of light in all directions, for it can be seen by a great number of persons at once.

Shadow and Penumbra.—An opaque screen placed before a luminous bundle prevents it from passing. From this results a *shadow*, which fills the whole space which would have been occupied by the intercepted bundle. If, for instance, the hand is held in the rays of the sun at a little distance from a wall, the shadow of the hand is seen on the wall. In proportion as the hand is moved away from the wall the outline of the shadow is less clearly defined. This is because the sun is not a luminous *point*, but a disc of sensible diameter, every point of which produces a shadow. The true shadow or *umbra* of the hand is that part of the shadow from which no portion of the solar disc is visible; and the *penumbra* the ill-defined border which surrounds the umbra.

If a sunbeam be allowed to enter a darkened chamber through a small square hole, or one of any other shape, a screen placed very near the hole receives an image of it on a shadowed ground; but if the screen be moved back, the image of the hole disappears in the penumbra, and a perfectly round image of the sun takes its place.

Images produced by small openings.—Effects of Diffraction.—Every luminous ray which meets an obstacle to its course forms an *image* there, and illuminates it. It is just the same with any union of rays. A luminous object—a candle-flame, for example—may be considered as made up of an infinity of luminous points, each of which sends a pencil of rays to our eye, so that an image of the flame is formed therein. Similarly, any external object—a church, for example (fig. 2)—may be considered as formed of an infinity of luminous points, each of which sends rays to all objects surrounding it. In fact, if we place ourselves facing the church in a darkened room having a small hole bored in the direction of the building through the window-shutter, we shall see an image of the church formed in an inverted position

upon a screen opposite the hole. For the rays emanating from the top of the steeple pass through the hole and light up the screen with their own colour; those emanating from the wall do the same; and so on with the rest of the building: thus an inverted image of

Fig. 2.

the church is formed on the opposite screen. If the hole in the shutter were very large, then each spot in the screen opposite would receive light from a great number of different and distant points of the object outside, all the images thus formed would overlap each other, and the image would be an ill-defined one. The smaller, therefore, the hole is, the sharper but fainter is the image; and conversely, the larger it is, the worse defined but brighter is the image. The size of the image evidently depends upon the distance of the church from the hole, or of the screen which receives the image from the hole.

When the external object possesses very great luminosity, and when the opening into the dark chamber is very minute, as, for example, when the image of the sun is received into the chamber through a thin sheet of copper pierced with a fine pin-hole, the image is perceived to be not sharply marked out, but surrounded by a series of coloured rings which confuse its outline. This phenomenon has received the nameof *diffraction of light.*

Opaque, translucent, and transparent bodies.—A body is *opaque* if it arrests the passage of rays which strike it; *transparent* if it allows them to pass freely. There are no bodies either absolutely opaque or absolutely transparent. Opaque bodies when reduced to sufficiently thin laminæ always transmit some of the light which strikes them; and *transparent* bodies in great thickness arrest part of the light

which traverses them, this action being what constitutes *absorption* of light by media said to be transparent. *Translucent* bodies are those imperfectly transparent. The metals are said to be opaque; glass, silicates, crystallized bodies, liquids and gases are generally transparent; organic substances non-crystalline in texture, such as wood in thin layers, horn, gold-beater's skin, &c., are translucent.

Absorption of Light by transparent media.—When a pencil of light falls on the surface of a transparent medium, a part of this pencil is reflected, and in quantity so much the greater as the surface of the medium is more oblique to the incident ray; another part is diffused through the medium; and, lastly, a third is transmitted. Supposing the incident ray to be perpendicular to the surface of the medium, absorption depends almost entirely on the more or less transparent nature of the medium, on its thickness, and on its tint. With respect to glass, which may be looked upon as sensibly colourless, *Bouguer* has found, that a thickness of six superposed sheets, forming a total thickness of only twenty-six millimètres, causes a loss of seven-tenths of the light. Only a third, therefore, of the light is transmitted; but, in this case, the great loss of light depends principally upon the reflection produced by the twelve surfaces of the medium.

The air itself arrests a certain part of the light emanating from the sun. *Bouguer* gives the following table of the *intensity of the sun's light at different elevations:* 10,000 would be the intensity of this light if air were *absolutely* transparent.

Sun's Altitude.	Intensity.	Sun's Altitude.	Intensity.
0°	6	20°	5474
1°	7	25°	6136
2°	192	30°	6613
3°	454	40°	7237
4°	802	50°	7624
5°	1201	70°	8016
10°	3149	90°	8123
15°	4535		

This table is very instructive, because it serves to show us the immense difference which exists between the intensity of the sun's light in summer and in winter. Thus, at Paris, on June 21st, the elevation of the sun at noon is about 64° 17′, and the intensity of his light is then, in round numbers, 7800. In winter, on the 21st of December, the sun's elevation is 17° 43′, and the intensity of his light is then no more than 5000, being but $\frac{5}{8}$ of what it is in summer. In this comparison the atmosphere is supposed to be very clear; but if we reflect that very often in winter, in our climates, the atmosphere is misty, we can easily understand the great difference in the intensity of the light radiated by this body in winter and in summer.

We have seen that the chemical rays of light, that is to say, that part of light (the blue and violet) which acts on photographic surfaces, differs from the illuminating (red and yellow) part of light. We have a very striking example of this in investigating the absorption of chemical rays by media, such as glass, very transparent to luminous rays. The more or less perfect *polish of the surface* is found, particularly, to greatly influence absorption. The more perfect the polish, the less considerable is the absorption, all things else being equal. This is explained by the well-known fact, that ground glass arrests a great part of the chemical rays of light; for a surface imperfectly polished is a surface slightly ground.

Secondly, absorption depends a great deal upon the colour of the medium. For this reason, glass completely colourless, like the light kind of flint-glass, allows two or three times as much chemical light to pass through as the very heavy kind, which is yellowish, and one and a quarter times as much as crown-glass, which is of a greenish tint.

When transparent plates are colourless they all transmit chemical light to almost the same extent. In consequence of this, lenses of the same shape in quartz, rock-salt, flint-glass,

and crown-glass show no difference in their power of transmitting chemical light.*

The thickness of the medium exercises a great influence on the absorption of the chemical rays (or such rays as act on photographic surfaces). The law discovered by *Bouguer* applies here as well as in the case of the absorption of radiant heat, namely, that the intensities of the transmitted rays form a decreasing geometrical progression when the thicknesses form an increasing arithmetical progression.

If the absorption were simply proportional to the thickness of the medium, a very thick layer of the medium would be opaque. Thus let us take, for example, sea-water. If a mètre of this absorbs one-twentieth of the incident light, twenty mètres will, on the above supposition, absorb twenty-twentieths, or the whole of the light, and at this depth there will be total darkness; but such is not the case. If the first mètre of water absorb one part out of 20 of incident light, there will be 19 which have traversed this medium; the second mètre will absorb only one-twentieth of these 19 parts, leaving therefore 18·05; the third mètre will absorb only one-twentieth of the 18·05 parts of light transmitted by the second, and so on; so that, even if a hundred, a thousand, or even a million mètres of water were traversed, there would still be a certain quantity of light transmitted, as in fact we find by experience. It follows from this, that, in a very thick transparent plate, the first layers, when traversed by

* The author has had constructed by M. Sécretan lenses, with a diameter of 1 inch and a focal length of 6 inches, in flint, white crown-glass, colourless quartz, and colourless rock-salt, and has compared them together by mounting them all in a camera and receiving the image of external objects on the same photographic surface. The four photographic images were of apparently equal intensity. Although these media, as Dr. Allen Miller has shown, exert a different absorbent power on certain rays of very high refrangibility (and situated entirely beyond the violet end of the spectrum), it does not therefore follow that they also absorb differently less refrangible rays, such as the blue, violet, and indigo, and thus Dr. Miller's experience in no way invalidates the results obtained by the author.

the incident light, absorb the greatest part of it, the others absorbing much less.

From this it also follows, that of two transparent plates, one of which is twice as thick as the other, the first will not absorb twice as much of the incident light as the second. On the contrary, the absorption will be nearly equal if the thickness of the plates do not exceed a few centimètres, and if they are without colour.

Reflection of Light.—A surface *reflects* when it sends back some of the light impinging upon it. All bodies reflect light more or less. However, by the name of reflecting surfaces are usually meant *polished* surfaces. But, even when a ray of light meets a perfectly polished surface, only some of it is reflected; for a part is absorbed by the medium which forms the substance of the polished surface, another is diffused, and another is transmitted if the medium be transparent.

The study of the reflection of light from the surface of polished plates bears the name of "*catoptrics.*" Let A B (fig. 3) be a plane reflecting surface, and R O a ray of light, incident upon it; that ray will be reflected in the direction O R′ in the same plane as the incident ray—the plane being perpendicular to the reflecting surface, and making with that surface an angle R′ O A equal to the angle R O B. The normal N O is the straight line perpendicular to the surface A B, which makes with the incident ray R O and the reflected ray R′ O equal angles.

Fig. 3.

In this way we can determine the path of light reflected from any geometrical surfaces whatever; but this study is quite foreign to the optics of photographic instruments.

Mirrors and their reflecting power.—A polished metallic surface is called a mirror. The quantity of light

reflected from the surface of a mirror depends on three elements: the degree of perfection of its polish, the colour of the surface, and the incidence of the luminous rays which strike it.

The more perfect the polish, the less is the loss of light in the act of reflection. Metallic surfaces being polished with great difficulty, and, besides, soon becoming tarnished in the air, we usually substitute for them plates of polished glass, backed up with mercury, or, still better, with silver. In this case the metal partakes of the admirable polish so easily given to glass.

On the colour of the metal depends, in great part, the colour and the intensity of the reflected ray. Thus copper, which is polished with difficulty, and the colour of which is red, reflects rays of light imperfectly, and gives to them its red tint. In the same way gold gives the reflected light a yellow colour. Of all metals silver is the whitest; this is why silvered glasses make the best mirrors. They reflect, according to M. de Steinheil, ninety per cent. of the incident rays; while glasses backed with mercury reflect only sixty-five per cent. And, as the sole employment of mirrors in photography is to send the solar rays into the apparatus for enlarging, and as the sun very soon destroys glasses backed with mercury, causing the mercury to run into globules, all the advantage is in favour of silvered glasses.

Lastly, the more obliquely the light falls on a reflecting surface, the less it diminishes in intensity by reflection. Further, if it falls so as to make a very acute angle with the reflecting surface it is *entirely* reflected. We have a very evident proof of this, in looking at a white object reflected by a polished plate of copper or of gold, which then appears red or yellow; but when we incline the plate in such a way as that the reflecting plane is directed towards the object, so that the rays emanating from it just graze the plate, the object will no longer appear coloured, but white. Now, this is because, in such a case, *the whole* of the light coming

from the object is reflected, no matter what may be the colour of the plate; in other words, the light suffers *total reflection.*

It is generally imagined that the more nearly the rays of light fall perpendicularly on a reflecting surface the greater is the portion of light reflected; but the contrary is the case. In fact, representing by 100 the intensity of the solar rays falling at an angle of from 60° to 90° (that is, nearly perpendicularly) on a quicksilvered mirror, the intensity of the solar rays reflected is 60; so that 40 per cent. is lost in the act of reflection. If, on the other hand, the solar rays make with the mirror only an angle of 5°, the intensity of the reflected rays is 70; so that there is only 30 per cent. of loss. With silvered mirrors, as we have seen above, the loss is much less.

Adjustible Mirrors.—The instruments which serve to reflect solar light in optical apparatus are called *adjustible mirrors.* We give here the description of two of the forms most frequently used.

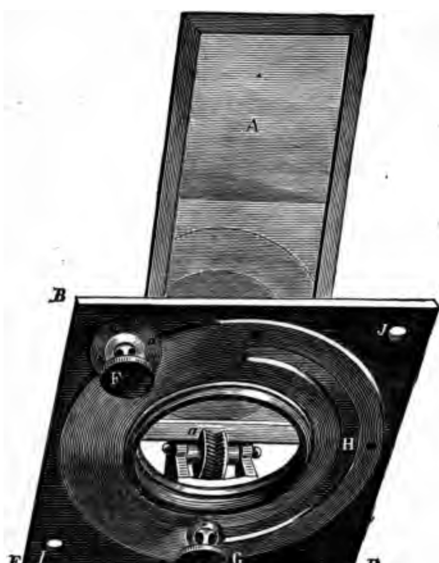


Fig. 4.

B C D E (fig. 4) is a square plate of bronze or iron, which is fixed by the screws J I to the shutter of a darkened room. This plate is pierced by a round opening, which receives a disc of the same shape, toothed at its periphery, and pierced at the centre by a

circular opening. Lastly, to maintain this disc in position, and to keep it from falling out, it is covered by another, attached to the square plate. A pinion, with milled head, F, works in the teeth of the circular disc, and enables us to turn it round.

To the revolving disc is attached a small arm, which is seen under the letter *a*. The mirror A is fixed into a small toothed wheel, the axis of which is held by the arm. A pinion, of which the milled head is seen at G, works in the small toothed wheel *a*, so that all imaginable inclinations to the plane B C D E can be given to the mirror; and as, on the other hand, the milled head F allows the disc to which the mirror is attached to be turned round, it follows that the mirror can receive all required positions.

This instrument, as we have said, is fixed to the shutter of the dark chamber. By turning simultaneously the milled heads F and G, the solar rays can be thrown through the opening in the centre into the dark chamber, and the desired direction, which is usually a horizontal one, be given to the reflected rays.

The circular opening which gives passage to the reflected rays ought to have a diameter equal to the breadth of the glass; but as to the length which the glass ought to have in order to reflect a cylinder of solar rays equal in diameter to the opening, this depends on the aspect of the shutter and the height of the sun above the horizon. The most convenient aspect is a southern one (a northern one in places situated in the southern hemisphere, as in the East Indies, Cape of Good Hope, &c.) The height of the sun depending on the latitude of a place, the higher the latitude the longer the mirror must be. In our climates (between 40° and 60° of latitude) it is sufficient if the length is three times the diameter of the aperture for the rays reflected by the mirror to cover the aperture in spring and summer (from March 1st to September 30th); but in winter, particularly in from 50° to 60° of latitude, this length is quite insufficient, and even a

mirror ten times longer than the dimensions indicated above would still be too short.

The adjustible mirror represented in fig. 5 is more convenient for winter, but it requires a special arrangement and a dark chamber, built expressly for it in a garden or on a terrace.

This chamber should be very low, in order that the solar rays may pass, even in winter, above the roof which covers it, the summit of which roof is directed towards the south, while the lowest part, raised at the most six feet from the ground, looks towards the north. The optical apparatus is no longer directed towards the south, but towards the north; and it is at two or three mètres to the north of the building that the adjustible mirror is placed, of which the following is the description:

Fig. 5.

The mirror L is either square, or, still better, circular. Its diameter ought to be double that of the lens on which the solar rays will be reflected. This mirror, mounted in wood, is attached by means of four screws to the ends of the toothed semicircle *K*, the (horizontal) axis of which turns in two uprights of

iron. A small toothed wheel, I, is in gear with the semicircle, and is placed a little on one side, for the rod *a* must occupy the vertical axis of the foot of the mirror, and it is from an endless screw which terminates this rod *a* that the small wheel I, and from it the semicircle K, receives its movement.

The fixed pedestal of the instrument is formed by the iron plate *c c* turned upon both its upper and lower faces, by the plate of cast iron H, and by the three feet D, of iron or wood, which join the two plates.

The rod *a* is terminated below by a small conical toothed wheel, the lower part of which turns in a small bearing fixed to the plate H. One extremity of the horizontal rod G passes into the dark chamber, where it terminates in a key-piece, which is moved by the hand; the other (seen in the figure above the letter H) ends in a conical toothed wheel working in that of the rod *a*. By turning, therefore, the rod G, movement is communicated to the rod *a*, and consequently to the wheels I and K, in such a way that the mirror receives a motion in a vertical plane.

The two uprights, E E, which sustain the mirror, are fixed on a plate of turned iron, of which the margin rests on the upper part of the plate *c c*, which presents a central circular opening equal to half its total diameter. The plate which carries the uprights, E E, can therefore turn freely on the plate *c*; but, to communicate movement to it from the dark chamber, another plate, B, is placed on its lower part, of which the toothed circumference works in the endless screw terminating the rod A which passes into the dark chamber. The plate *c* is therefore held, with gentle friction, between the margin of the upper plate and the plane of the toothed wheel B, so that the system of uprights E E is solid; the plates also give free passage to the rod *a*. The mirror, in addition to the movement in the vertical plane, has therefore a movement in the horizontal plane also; so that, in relation to a given point, it can take all positions imaginable.

The reflecting part of the mirror being turned towards the

sun, it suffices to communicate from the dark chamber a convenient movement to the rods A and G, in order that the solar rays may be reflected horizontally into the optical apparatus.

Heliostats.—Heliostats are adjustible mirrors which receive their movement from clock-work in such a manner that the solar rays reflected remain motionless in a given direction.

As the minute description of those instruments, the use of which in photography is important, occupies a very considerable space in this work, a special chapter has been devoted to it, which will be found in the book treating of enlargements.—(See the Table of Contents.)

CHAPTER II.

REFRACTION OF LIGHT.

THE study of the path of light through transparent media bears the name of "*dioptrics.*" This study, which is very complicated, extends to all imaginable media, crystallized or amorphous, transparent or opaque, liquid, solid, or gaseous. We have, however, but to consider, and shall only in this work treat of, one class of transparent media, namely, the non-crystalline, and more especially glass.

Refraction of Light.—Light, in consequence of passing from one medium into another, is *refracted*—it changes its velocity. If it fall *normally* (that is to say, perpendicularly) on the surface of a medium, it continues through this medium its course in a straight line, although refracted. But if it fall obliquely, its direction is changed, and it deviates from its rectilinear path. As an example, we may cite the case of a stick which, when plunged half-way into water (fig. 6), appears broken at its point of contact with the water.

The point where the incident ray cuts the surface of the *refracting* medium is called *the point of incidence* or *point of immersion.* The name of point of *emersion* or *emergence* is given to it when the ray is leaving the refracting medium. The angle which the refracted ray makes with the *normal* (or perpendicular) to the surface of the refracting medium has received the name of *angle of refraction.*

Fig. 6.

Law of Refraction.—1st. *The incident ray, the refracted ray, and the normal, are all in the same plane.* 2nd. *For the same two media, the ratio of the sine of the angle of incidence to the sine of the angle of refraction is constant, whatever may be the angle of incidence.* This law has received the name of "the Law of *Descartes.*" Let us give an example of it:—

A ray of light, R O (fig. 7), passing from air into water, is refracted along O R′, in the same plane as the incident ray. If, at the point of immersion O, where the incident ray R O touches the water, we raise a perpendicular, or *normal*, A B, to the line *n m*, which represents the surface of the water, we shall find that the refracted ray is bent towards it. Conversely, a ray, R′ O, passing from water into air is refracted in a direction, O R, which bends away from the *normal.* For air and water, the ratio of the sines of the angles R O A and R′ O B is constant, whatever may be the incidence of the ray R O.

Fig. 7.

Index of Refraction.—If, in place of water, we use essence of turpentine, ether, or other liquids, we shall always find for the same liquid a constant ratio between the sine of the angle of incidence and the sine of the angle of refraction; but this ratio differs *with the nature* of the liquid, being, for example,

much greater for ether than for water, and therefore ether is said to be more refractive than water. This ratio has received the name of *index of refraction.* The higher therefore the index of refraction possessed by a medium—in other words, the more refractive it is—*the more it deviates the incident luminous ray from its primitive direction.*

Works on physics,* particularly works on optics, contain different methods by the aid of which the index of refraction of transparent substances can be measured; it is therefore not necessary to describe these methods here. We shall only remark, that (as we shall afterwards see) the refraction of white light is always accompanied by *dispersion*, that is, by decomposition; and that, ordinarily, the ray which corresponds to the yellow is taken for the refracted ray. We shall, however, return to this subject.

The following is a table of the index of refraction of a few substances:—

Vacuum..	0·000
Diamond	2·47 to 2·75
Flint-glass†	1·57 to 1·60
Rock-crystal	1·547
St. Gobain glass (crown)‡	1·5
Congealed water (ice)	1·31
Liquid water (at 0° C.)..	1·333
Liquid water (at 20° C.)	1·332

Refraction by transparent plates with parallel surfaces.—Let fig. 8 be a transparent plate with parallel faces —a sheet of glass, for example,—and R a ray of light incident upon it. The ray, which would pursue its course in a right line if the glass were not in the way, suffers deviation towards the normal, N, on entering the plate, and away from

* See Daguin, *Traité de Physique*, tome iv. p. 155 (2nd edition).

† There are varieties of flint-glass, containing lead, of which the index of refraction is even higher than 1·6.

‡ The index of refraction of crown-glass varies also with the composition of the glass; it is most often higher than 1·5.

it again on leaving it. Now, since the sheet of glass, taken as an example, has its faces parallel, it follows that the normals N and N′ are also parallel. As it is easy to conceive, the deviation on leaving the glass is precisely equal to the deviation on entering it, and the ray R is parallel to R′; therefore, *when a refracting plate with parallel faces is placed in the path of a luminous ray, the ray preserves its direction, although its first position is changed.* It is evident that if the ray fall perpendicularly on the glass plate, along N for example, it would leave it without deviation, because it is coincident with the normal.

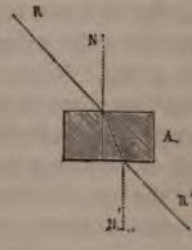


Fig. 8.

In place of a plate of glass, one of rock-crystal, rock-salt, or any other transparent material, may be taken for illustration. In using these materials, for the same thickness and inclination of the plate to the incident ray, the displacement will be variable in extent, because their refractive power is different.

Refraction by Prisms.—Let us now consider the case of refracting media, with plane faces inclined to each other, such media having received the name of *prisms.*

Let C A B (fig. 9) be a prism, and R *o* a ray of incident light. On entering the prism, this ray is deviated along *o o′* (unless it fall perpendicularly on the face A C), and on leaving the prism it is again deviated along *o′* R′. The two deviations on entrance and exit are identical as regards the normals N *o*, N′ *o′*, as in the example of the plate with parallel faces; but as the faces A C, A B here make an angle with each other, the two

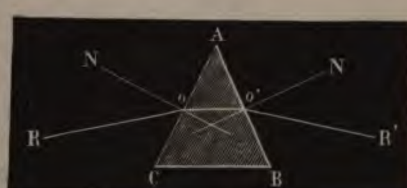


Fig. 9.

rays, R o and o' R′ will also make an angle with each other. But this angle will not be the same as that (C A B) of the prism, for it depends on the refractive power of the material which forms the prism, and on the size of the angle (C A B) of the prism. Prisms, then, deviate towards their base rays incident upon one of their faces.

Graphical construction of a ray refracted by a Prism.—This is very easy when the index of refraction of the material of the prism is known. Let it, for example, be supposed to be glass with an index of 1·5. This index is absolute, that is, expressed in relation to a vacuum, but, as in most cases, the luminous ray has passed through the air, it would be necessary to take into account the index of refraction of this medium, were it not that it is so small that it may nearly always be neglected.

Draw on a sheet of very smooth Bristol-board the angle A (fig. 10), which forms the edge of the prism. At the point of immersion o, draw the normal N o perpendicular to the right line A C, which represents one of the faces of the prism. Let R o be the incident ray, making with the normal N a given angle. From any point R on the incident ray, let fall on the normal the perpendicular N R, which is the sine of the angle of incidence N o R. Make N a in the ratio of unity to the index of refraction, which in the present example is the ratio of 1 to 1·5 or of 2 to 3. Therefore, make N a equal in length to two-thirds of N R. Draw the right line $a\,o$, which represents the *refracted ray*.

Fig. 10.

In o', the point of intersection of $a\,o$ prolonged, with A B (the other face of the prism), raise the normal N′ o' perpendicular to A B. From any point a, on the refracted ray $a\,o'$,

let fall on the second normal $N'o'$ the perpendicular aN'; this is the sine of the angle of incidence. Prolong the sine to b', so that $aN'=2$ and $N'b'=3$, and draw the right line $b'o'$, which, when prolonged, will give $o'R'$. This is the emergent ray.

The explanation of this diagram is simple. It is necessary to effect for the face A B the converse of what is done for the face A C. Now, R N is the sine of the angle of incidence, and N a the sine of the angle of refraction. The ratio of these is known, for it is the index of refraction. If, then, the lengths of N a and N R are made corresponding to this ratio, the refracted ray ao' is evidently obtained. By proceeding similarly, but in the inverse way, to get the emergent ray, O′ R′ is obtained.

Calculation of the refracted Ray.—Let M N (fig. 11)

Fig. 11.

be the incident ray, making the angle of incidence i with the normal B N D; N P the refracted ray, making the angle $PNC=r$ with the same normal; P Q the emergent ray, making the angle $EPQ=r'$ with the normal P E to the second face; $NPC=i'$ the angle of incidence of N P with this normal, a the angle of the prism, and n the index of refraction:* the incident ray M N prolonged will meet the

* In England the index of refraction is generally symbolically represented by the Greek letter μ; on the Continent it is invariably, as in this treatise, represented by the letter n.

emergent ray P Q in F, and the angle G F Q of these two rays will be the angle of deviation d, which has to be calculated.

Now, in the triangle P F N, the sum of F N P+F P N is equal to the exterior angle d, therefore $d = \text{F N P} + \text{F P N} = (i-r) + (r'-i') = (i+r') - (r+i')$; but the angle D C P of the two normals is equal to the angle a of the prism; further, in the triangle N P C, the sum of $r+i$ is equal to the exterior angle a; we have, therefore,

$$d = i + r' - a \text{ . . . . . } (1).$$

By another calculation, the laws of refraction give the formulæ—

$$\text{Sin } r' = n \sin (a-r) \text{ . . . . . . } (2).$$

$$\text{Sin } r = \frac{\sin i}{n} \text{ . . . . } (3).$$

The formulæ (1), (2), and (3), are general, and enable us to calculate the deviation of any incident ray, situated in a plane perpendicular to the edge of the prism: for, the angle of incidence i and the index of refraction n being known, the angle r can be found by formula (3); knowing this, and the angle a of the prism, we can calculate r' by the aid of formula (2), and after that we may eliminate d by formula (1).

If the angle a be very small, and the incident ray be nearly perpendicular to the bisector of this angle, then i is also a very small angle. In formula (3) the ratio of the sines may be replaced by that of the arcs, so that we have $r = \frac{i}{n}$; for the same reason, formula (2) gives $r' = n\ (a-r) = n \left(a - \frac{i}{n}\right) = na - i$; and, in consequence, formula (1) becomes

$$d = i + r' - a = i + (na - i) - a = (n-1)\ a.$$

If, a being very small, the incident ray be not nearly perpendicular, but oblique, to its bisector, then the angle i ceases to be very small, and the simplest means of calculating d is to make use of formulæ (1), (2), and (3).

CHAPTER III.

CHROMATICS.

Hitherto we have considered the passage of light through transparent media, from a geometrical point of view only, as if a ray of incident light gave rise to but a single refracted ray. This is true, were the *simple* ray *homogeneous*, that is, of a *simple colour*, (we shall see presently what this term means); but if the incident ray be composed of white light instead of a single refracted ray, then, after refraction an infinity of refracted rays is obtained—a phenomenon which has received the name of *dispersion*.

The Solar Spectrum.—Into a dark chamber, suitably arranged, let a bundle of horizontal solar rays a (fig. 13), be

Fig. 12.

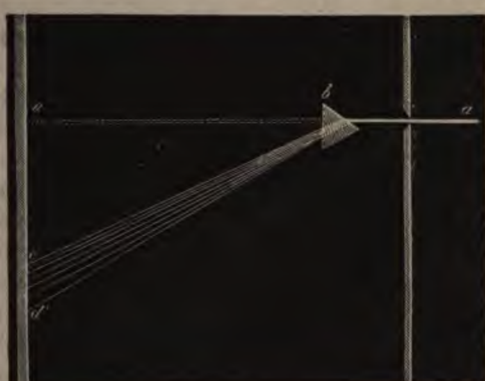


Fig. 13.

allowed to enter through a circular hole one centimètre in diameter, by means of an adjustible mirror. A round image of the sun a' (a'' in fig. 12) will thus be formed on the wall opposite

the shutter. If, in the path of the rays $a\,a'$, a glass prism be placed in the position shown in the figure, instead of getting, after refraction of the rays, a circular white image as before, we obtain at $c'\,d'$ ($c\,d$ in fig. 12) an elongated and coloured image called the *Solar Spectrum*. This *spectrum* is composed of the following colours, beginning from above—red, orange, yellow, green, blue, indigo, violet. The red, being less deflected than the violet, is said to be *less refrangible*. Each of these colours is called "*simple*," because if a bundle of rays of one of them be isolated, by passing it through a hole in the centre of a disc of blackened copper, and received on a second prism, it is of the same colour after this second refraction.

The coloured rays which emerge from the prism are unequally refrangible—that is to say, if they fall at the same angle of incidence on the surface of a refracting medium they will each pursue, in this medium, a different path. Thus, in the example of the refraction of an incident ray by a transparent medium quoted at page 17, if R O be a red ray of which O R′ is the refracted ray, O R′ would approach nearer to the normal O B if R O were violet, because the violet is more refrangible than the red.

When it is wished to study with care the physical constitution of the solar spectrum, or the action of the spectrum on substances sensitive to light, it is necessary, in order to produce a suitable spectrum, to make the following arrangements.

In the shutter of a room completely darkened (fig. 14) a plate of brass is placed vertically, having a rectilinear aperture, very narrow, (not less, however, than one millimètre), and two or three centimètres high. Two thin plates of copper which form the opening are also made moveable and capable of being separated or approximated, according as the spectrum is to be more or less intense.

The solar rays are reflected horizontally through this rectilinear opening by a plane mirror of silvered glass, polished on its upper surface. If wished, an ordinary mirror may be employed; but in this case a part of the chemical rays

of light is absorbed by its passage through the glass of the mirror.

The prism (of which the section is an equilateral triangle) of flint-glass, quartz, or any other transparent material, and mounted on a foot resting on three screws, is placed vertically in the path of the luminous ray. The luminous band must fall on only one of the faces of the prism, and near its edge. The vertical position of the prism is tested by comparing the height of the spectrum with that of the slit above the floor; the two heights ought to be equal.

Fig. 14.

On turning the prism upon its axis (and its mounting is disposed so as to easily permit such a movement), the spectrum is seen to approach the luminous ray $a\,a'$ (fig. 13), but a point is soon reached when it begins to move away again from it, even on turning the prism in the reverse direction. There is, therefore, a position of the prism, called the position of *minimum of deviation*,* which it is essential to fully realise, else

* In this case, the angle of dispersion is the smallest possible, and the spectrum the shortest possible. To realize this position of the prism, the incident ray R o (fig. 9) and the emergent ray o' R′ must make equal angles with the bisector *of the* angle A of the prism.

the colours of the spectrum will be mixed with white light.

The spectrum thus obtained has not a sharply defined outline, but on receiving it into a photographic apparatus,* through a double objective, as shown in fig. 14, the slit can be brought to a focus through the prism, and when this is done it takes a rectangular form. By moving the rack-work of the objective, the different colours may be successively brought to a focus, for the focus of each is different.

The camera which serves to receive the spectrum must be capable of being shortened and elongated to a sufficient extent, and must be supported by a stand susceptible of the movements necessary to place it horizontally. The ground-glass screen should be about ten centimètres high by fifty broad.

The prism must always be placed as near as possible to the objective.

The nearer the objective and the prism are approximated to the slit, the broader and longer is the spectrum; and the further they are moved from it, the smaller and brighter is the spectrum. It follows from this, that when experiments are to be made on the chemical action of the spectrum with substances very sensitive to light, the first arrangement is to be employed; and with those, on the contrary, little sensitive, the second. In the first case, this spectrum should be three or four decimètres long; in the second, one decimètre, and in this case the slit in the shutter may even be a little enlarged.

The various colours of the solar spectrum are more or less elongated, according to the dispersive power of the prism employed. We have already named the principal colours of which it is formed; we may now mention that *Sir John Herschel* has added to these two others, very difficult to observe well, but which, however, are to be seen if the

* The reader is here supposed to be familiar with the practical proceedings of photography.

chamber is well darkened: they are, the one crimson, beyond the red; the other grey (crimson and lavender) beyond the violet.

Lines of the Spectrum.—When the solar spectrum, produced in the way we have just described, is examined with attention, an infinite number of dark lines in the direction of its breadth are to be observed, which were discovered by *Wollaston* and *Frauenhofer*. These lines, for solar light, and the same refracting substance, always have the same relative order—a fact of the utmost value, because these lines serve to specify exactly the parts of the spectrum in which they occur.

In fact, the passage from one colour into another being insensible, the designation, yellow, red, &c., is vague. Precision is obtained by stating the line or group of lines which exactly characterise the place of that part of the spectrum which it is wished to indicate.

At M. Sécretan's, optician, Pont Neuf, à Paris, a coloured lithograph of the spectrum may be obtained, which contains all the principal lines of the spectrum with their designations. This plate, which is more thân a mètre in length, and of which the price is only six francs, is indispensable to every one studying optics.

Chemical action of the Spectrum.—Extra-prismatic Rays.—We have already spoken of the chemical action of light at p. 3.

If chloride-of-silver paper be exposed for some minutes to the action of the solar spectrum, kept motionless, and if, from time to time a ground-glass be interposed between the spectrum and the prism (which permits the successive action of the light, otherwise invisible, to be seen), it will be found that the action begins in the indigo and violet, and then passes on into the blue, and far beyond the violet, where, nevertheless, no light can be distinguished by the eye. In the red, orange, yellow, and green there is no action at all, so that the paper at that part remains white.

On substituting for the silver-chlorised paper, a paper of

the bromide of the same metal, the action extends a little way into the green.

Figure 15 represents this experiment. The rectangle on the right of the figure represents the seven colours of the spectrum, of which the names are printed on the left. The dark rectangle on the left represents a strip of silver-bromised paper, and the next rectangle a paper of the chloride of the same metal, after having been both submitted for a long time to the action of the spectrum.

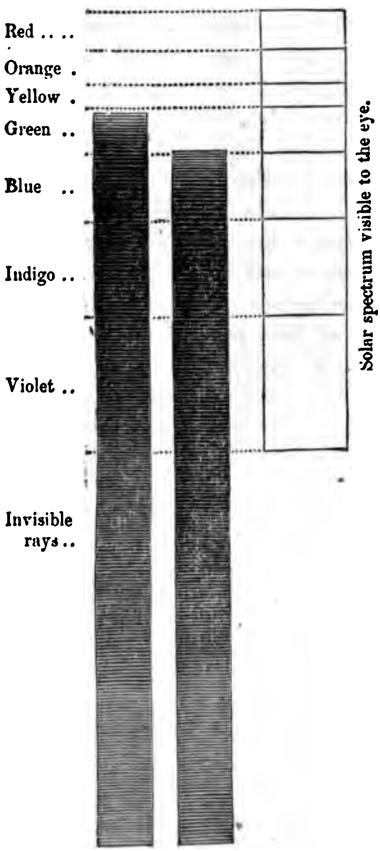


Fig. 15.

Most substances sensitive to light behave in the same manner. The experiment is of the highest importance in photographic optics. It demonstrates at once, that the most brilliant colours of the spectrum, that is, those which are most diffused throughout nature — namely, the red, orange, yellow, and green —have no action on substances sensitive to light; and that, on the contrary, the colours the least brilliant—blue, indigo, and violet—have on these substances a very intense action (the maximum being in the indigo); and, lastly, that

there exist in solar light, rays invisible to the eye, which have on these substances a very intense action also. These invisible rays have received the name of *extra-prismatic rays.*

On the colour of Bodies.—Bodies in nature, illuminated by solar light, present all colours imaginable. This is because the light of the sun, or that of the clouds, which strikes them is decomposed at their surface; they absorb all the simple rays of which white light is formed, except those they reflect. White bodies reflect all rays which strike them; black bodies absorb all.

Coloured bodies, however, absorb only a part of the coloured rays which strike them, a great part of the white light which illuminates them being reflected in a diffused state, and without being decomposed. It is more especially red, yellow, and green bodies which act in this way, and it is owing to this property that they are reproduced on *photographic surfaces.** Blue and violet bodies, which, on the contrary, scarcely reflect any white light, are, on the other hand, very *photogenic* or *actinic.*†

Blue and violet are even so photogenic that they are reproduced on photographic surfaces as if they were white. Red and yellow are so little so that they are reproduced as if they were black. There are, however, ways of modifying these phenomena so as to make the reproduction of colours more conformable to truth. (See *Traité général de Photographie,* 5th edition, p. 28).

Dispersion.—We have already defined the term *dispersion,* p. 18. The dispersion of refracting media is measured by the length of the spectrum which is furnished by them. Thus flint-glass is said to be more dispersive than crown-glass,

* We employ this term to indicate the surfaces of iodide, bromide, chloride of silver, &c., of which photographers make use, and which, as is well known, are very sensitive to light (which blackens them).

† Terms used by photographers to indicate rays of light having a powerful action on *photographic* surfaces.

because the spectrum which it furnishes is longer than that of crown-glass.

Yellow, being the most brilliant colour of the spectrum, is that which approaches nearest in intensity to white. It is also the ray of this colour which has been selected as the refracted ray in measuring the refractive power (index of refraction) of transparent media, the incident ray being white. All indices of refraction given in tables are therefore too high if the refracted ray under consideration is red, and all are too low if the ray under consideration is violet; seeing that, out of the infinite number of refracted rays to which a white ray gives rise, the red is that which is the least refracted, and the violet the most.

But the numerical value, to express which all these indices are too high for red and too low for violet, varies with the nature of the medium to which the index refers, according as the different media elongate more or less the colours of the spectrum.

The *co-efficient of dispersion* (or simply the *dispersion*) of a medium is indicated by the difference between the index of refraction of the red (or of the yellow in photographic optics), and the index of the violet, (of the indigo in photographic optics).

No.	Names of Substances.	Density.	Index of Refraction.
1	Heavy boracic acid flint-glass (Guinand) ..	3·417	1·72339
2	Flint-glass (Frauenhofer)	2·135	1·63913
3	Flint-glass (Bontemps)	2·011	1·62847
4	Ordinary flint-glass (Guinand)	3·610	1·62730
5	Boracic acid flint-glass (Guinand)	4·322	1·62696
6	Venetian glass	2·713	1·53445
7	Boracic acid crown-glass (Guinand)	2·362	1·53455
8	Crown-glass (Dollond)	2·484	1·53113
9	Boracic acid glass with a base of zinc (Maës)	2·835	1·52401
10	Crown-glass (Bontemps)	2·447	1·51921

No.	n_h	n_g	n_f	n_e	n_d	n_c	n_b
1	1·7637	1·7486	1·7320	1·7234	1·7144	1·7070	1·7049
2	1·6679	1·6573	1·6454	1·6392	1·6324	1·6272	1·6256
3	1·6558	1·6457	1·6346	1·6285	1·6222	1·6172	1·6154
4	1·6542	1·6443	1·6331	1·6273	1·6209	1·6160	1·6144
5	1·6539	1·6439	1·6328	1·6270	1·6205	1·6158	1·6140
6	1·5480	1·5433	1·5375	1·5344	1·5309	1·5284	1·5273
7	1·5478	1·5430	1·5374	1·5345	1·5311	1·5285	1·5275
8	1·5444	1·5393	1·5341	1·5311	1·5277	1·5247	1·5240
9	1·5466	1·5325	1·5271	1·5240	1·5207	"	"
10	1·5322	1·5275	1·5222	1·5192	1·5160	1·5134	1·5124

This table gives for the above ten kinds of glass the indices of refraction of the seven lines of the spectrum of Frauenhofer.

In treatises on physics, the index of refraction is designated by the letter n. And when regard is to be had to dispersion, the colour of the refracted ray selected for the index of refraction is indicated by a small letter at the side. Thus n_r, n_b, n_v, express the index of the red, the blue, the violet; or, if greater exactitude be desired, at the side of the n is placed the letter indicating the line in the spectrum whence the refracted ray has been taken.

We shall see, further on, for what end this is necessary.

The two preceding tables give—the first, the indices of refraction of ten kinds of glass; and the second, the variable index for each kind in reference to the line of the spectrum indicated at the side of n.

The *angle of dispersion* is the angle under which the different rays are elongated. The *dispersive power* is the ratio of the dispersion to the index of refraction shortly so called, minus 1. It is written, therefore: $\dfrac{n_v - n_r}{n_y - 1}$.

Achromatic Prisms.—A system of prisms is achromatic when it deflects rays of white light without colouring them.

An achromatic prism (fig. 16) is obtained by associating with a prism of crown-glass, A B C D, a prism of flint-glass, C D F E, the angle of which and the material are suitably

chosen. If in such a system an incident white ray, R o, falls on the face, A B, of the prism of crown-glass, the refracted ray will be decomposed, and $o\,r$ will be the red refracted ray, and $o\,v$ the violet refracted ray. On entering the flint-glass prism the violet ray will take the direction $v\,o'$, and the red the direction $r\,o'$; so that the emergent ray, o' R$'$, will be colourless.

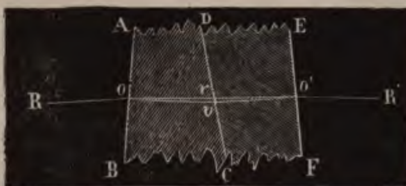


Fig. 16.

It is to be observed that the compound prism, which is achromatic, for the ray R o, or for rays of the same incidence, *would not be achromatic for rays of another incidence.*

We propose now to find the angles which the two prisms ought to have, in order that their union may constitute an achromatic prism. Because this investigation is only the introduction to that of achromatic lenses, we shall suppose the angle a of these prisms so small, that the deviation, D, which they produce on incident rays is equal to $(n-1)\,a$; n being the index of refraction of the material of which they are made. Further, we shall suppose the rays which traverse them to be very nearly perpendicular to the plane bisector of their angle a.

We have for the deviation D of the red by the two united prisms,—

$$D=(n_r-1)\,a+(n'_r-1)\,a',$$

n_r being the index of refraction of the red for the first prism, of which the angle is a; n'_r that of the second, of which the angle is a'.

For the deviation D$'$ of the violet we have—

$$D'=(n_v-1)\,a+(n'_v-1)\,a'.$$

Since these deviations must be equal, we have—

$$(n_r - 1)\, a + (n'_r - 1)\, a' = (n_v - 1)\, a + (n'_v - 1)\, a',$$

whence we get—

$$(1) \ldots \ldots \frac{a'}{a} = \frac{n_r - n_v}{n'_v - n'_r}$$

The angle a is known, seeing that it is chosen arbitrarily; a' will therefore be negative (that is to say, the second prism must be reversed in relation to the second), for $n_r - n_v$ is negative, whilst $n'_v - n'_r$ is positive.

But if the *dispersive power* of these two prisms be but slightly different, their union will form a plate with faces sensibly parallel, which will scarcely deflect rays of light, a result which it is necessary to avoid.

Let us write, therefore,

$$\frac{D}{(n_r - 1)\, a} = 1 + \frac{n'_r - 1}{n_r - 1} \cdot \frac{a'}{a}$$

For, when we consider that experience proves that the yellow is always very close to the red in the solar spectrum, and that consequently n_r is sensibly equal to n_y, we can write:

$$\frac{D}{(n_r - 1)\, a} = 1 + \frac{n'_y - 1}{n_y - 1} \cdot \frac{a'}{a}.$$

Replacing $\frac{a'}{a}$ by its value above given, and indicating, by p and p', the dispersive powers, $\frac{n_v - n_r}{n_y - 1}$ and $\frac{n'_v - n'_r}{n'_y - 1}$, of the two prisms, this becomes—

$$(2) \ldots \ldots D = a\,(n_r - 1)\left(1 - \frac{p}{p'}\right).$$

This value, D, would still be nothing, if the dispersive powers p and p' were equal, or slightly different; but in practice the kinds of glass selected are such as experience shows to be suitable for this object, namely, a colourless crown-glass, *very slightly dispersive* but strongly refractive, and a

light* flint-glass, nearly colourless, and rather highly dispersive.

The preceding formulæ give, therefore,—the first (1), the relative angle of the two prisms; the second, the deviation that their combination will produce in incident rays. A white ray will emerge sensibly white from such a compound prism, which will therefore be achromatic.

Photographic achromatism or actinism. — But, for photography, the preceding formulæ must undergo a slight modification; for the two kinds of rays that must be brought to coincide are not the red and the violet, but the yellow, the dominant colour of the spectrum, and the indigo, where the maximum chemical action of the spectrum is found. The dispersive powers must therefore be written—

$$\frac{n_i - n_y}{n_y - 1} \text{ and } \frac{n'_i - n'_y}{n'_y - 1}$$

And the first formula (1) becomes

$$\frac{a'}{a} = \frac{n_i - n_y}{n'_i - n'_y}.$$

This obliges opticians to select for photographic instruments special kinds of crown and flint glass, different from those required for astronomical objectives.

In all cases, the achromatism determined by calculation is never exact; because for this it would be necessary to have an accurate knowledge of the indices of refraction, and the dispersive powers, which the methods employed for this purpose do not give. Further, the angle of the prism should be *infinitely* small, (and it has always an angle relatively large); and, lastly, the incident rays have not, as they should have, a constant direction perpendicular to the plane bisector of the angle of the prisms. But the optician modifies by practical experience the results furnished by calculation. With two prisms, only two colours can be achromatised, or at most three,

* The heavy kinds of flint-glass would suit better, but they are generally yellow-coloured, which is above all to be avoided in photographic objectives.

by a good selection of the flint and crown glass; for, to obtain complete achromatism it would be necessary that the ratios of dispersion of the substances which form the prisms should be equal in all parts of the spectrum; and, hitherto, no such substances have been discovered. But two prisms, suitably chosen as to angle and material, are sufficient for practical purposes.

CHAPTER IV.

LENSES.

SECTION I.—*Definitions relating to Lenses.*

Convergent and divergent Lenses.—Lenses are transparent media, bounded by spherical surfaces, of which the intersection is a line without sensible thickness. The latter condition is important, as otherwise we should have a prism with spherical surfaces, and not a lens.

Lenses are divided into two very distinct classes: the first contains *convergent lenses*, thicker at their central part than at their margins; the second, *divergent lenses*, thinner, on the contrary, at their central part than at their margins.

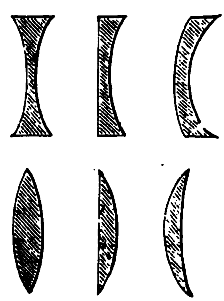


Fig. 17.

Figure 17 represents in section the different kinds of lenses; the three upper being divergent, and the three lower convergent. The first (that on the left) is *bi-concave;* the second, *plano-concave;* and the third has received the name of a *divergent* meniscus; the

fourth is *bi-convex;* the fifth, *plano-convex;* and the sixth is a *convergent meniscus.*

Principal axis and optical centre of Lenses.—The right line *a a'* (fig. 18), which joins the *centres of curvature a* and *a'* of the spherical surfaces of a lens, is the *principal axis* of the lens. If one of the faces of the lens be plane, the principal axis passes through the centre of curvature of the spherical face, and is perpendicular to the plane face.

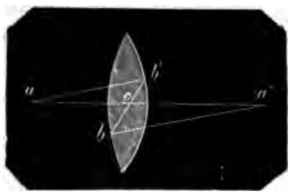


Fig. 18.

For every lens there exists a point, situated in its principal axis, so that every incident ray which passes through it does not undergo deviation. This point is called the *optical centre* of the lens.

To find the optical centre of a lens (fig. 18), through the centres of curvature *a* and *a'* of its surfaces draw two radii *a b'* and *a' b* parallel to each other but oblique to the axis *a a'*, then join their extremities *b b'*; this line will cut the principal axis at *c*, which is the optical centre.

If the lens be a meniscus, prolong the straight line *b b'* to the point where it meets the principal axis, which will be the optical centre.

The same construction gives the optical centre of bi-concave and divergent meniscus lenses. As to plano-convex and plano-concave lenses, the optical centre is determined by the intersection of the spherical surface with the principal axis.

A straight line passing through the optical centre of a lens, and making with the principal axis an angle more or less large, is called the "*secondary axis.*"

SECTION II.—*Manufacture of Lenses.**

Manufacture of Optical Glass.—It is a preliminary necessity for the manufacture of lenses, to have a good homogeneous glass, free from striæ, perfectly colourless, and transparent. Bubbles, lines, and even the presence of opaque particles in glass, merely intercept a portion of the light proportional to their size, whilst striæ are a certain indication of an imperfect mixture of the substances composing the glass, and are productive of unequal refractions. These striæ may be compared to those produced by the mixture of two solutions of unequal density, such as gum-water and pure water, alcohol and water, &c. The best way to see if a glass lens is free from striæ is to mount it in a wooden frame, which is fixed to the shutter of the dark room in such a way that it may receive the daylight. The eye being placed at the focus of the lens, the smallest striæ are easily perceived. Veins in glass may also be discovered by looking at it very obliquely opposite a feeble light in a well-darkened room.

Transparency of the glass is a condition essential for a lens; if within it there exists a cloudiness, it will be useless. It should also be colourless. Certain kinds of glass are yellowish (particularly flint-glass), reddish or greenish (crown-glass), and thus arrest—especially the yellowish and reddish kinds—a considerable part of the chemical rays of light.

There are great difficulties in obtaining discs of glass of large dimension quite free from striæ. At present, however, a great part of these difficulties has been overcome, and there

* PRETCHL, *Praktische Dioptrik.* Vienna, 1828.
SMITH, *Treatise on Optics*, 1767.
LABOULAYE, *Dictionnaire des Arts et Manufactures*, tome ii., art. *Verre.*
HERSCHEL, *Treatise on Optics.*
HERSCHEL, *The Telescope* (*Encyclopædia Brit.*), 1861.
H. RAPIN, *La Lunette d'approche.* Lausanne, 1861.

are to be had, for photographic purposes, discs of crown-glass at from five to six francs per kilogramme, and discs of flint-glass at fourteen francs per kilogramme,* for sizes of from one to six inches in diameter. Crown-glass more commonly costs from three to six francs per kilogramme; but then it is greenish, and always contains some striæ, particularly when the discs are of large dimensions.

Bontemps and *Guinand* are the two makers of optical glass who have done the most to advance this branch of industry.

The *crucibles* employed for the fusion of optical glass are of sorted fire-clay, capable of receiving a charge of about 250 kil., with covers to keep out the smoke, and having somewhat the form of very short-necked retorts.

The furnace is vaulted, and capable of being raised to a very high temperature. The crucible, well covered, is first heated to whiteness in the furnace; then, when the fuel ceases to give off smoke, it is charged successively with 10, 20, or 40 kil. of material, and after each charge the crucible is covered again, to avoid the smoke (putting the charge into it only when the fuel does not emit smoke). At the end of from eight to ten hours the furnacing is finished. The crucible being now raised to a white heat for four hours, the material is stirred for some minutes with a rod of pottery-clay attached at its upper extremity to a bar of iron. Six times, from hour to hour, the stirring is repeated, smoke always being avoided. Then the heat is reduced, in order that the bubbles of the melted mass may rise to the surface. At the end of two hours, the furnace is again raised to full activity for five hours, so that the glass regains its fluidity. It is again stirred for two hours, the stirring-rod is removed from the crucible, which is then closed up, as also the various openings

* At M. Sautter's, manufacturer of glasses for light-houses, Avenue Montaigne à Paris; also at Chance and Co.'s of Birmingham. French makers generally use glass of the former kind; English makers that of the latter kind. But many foreign opticians already ask for glass of French manufacture, the prices of which are lower, while the material is very perfect.

of the furnace, and, lastly, all is left to cool for eight days. The crucible is taken out and broken, and the mass of glass divided into pieces. The operation is the same for flint-glass as for crown-glass.

The divided pieces of the mass of glass are examined and sorted. The purest are used for astronomical objectives, the next quality for photographic objectives, and a third for ordinary lenses; the rest being waste, which is added to the next meltings.

The pieces are then softened in a kind of muffle, and made into square plates of a variable thickness (commonly of from half an inch to two inches).

The plates destined for astronomical objectives are ground with wet sand in cast-iron grinding tools, to give them pretty nearly the shape indicated by theory. As regards the other plates, they are softened by heat, and cast in moulds of clay or of iron, coated with sand, so as to give them very nearly the form which they must have. There may be formed in this operation streaks and striæ in the glass, and therefore opticians prefer grinding to moulding. For the large lenses employed as condensers in apparatus for enlargements, moulding is had recourse to, striæ in these lenses not having very troublesome consequences.

The following is the composition of the glasses of *Guinand* and *Bontemps*.

FLINT-GLASS.

	Bontemps.	Guinand.
White silicious sand	261	225
Red oxide of lead	261	225
Potash (1st quality)..	60	52
Borax	18	4
Nitre	..	3
Manganese	..	1
Arsenious acid	..	1
Waste pieces resulting from previous meltings ..	..	89

CROWN-GLASS.

	Bontemps (1846).	Guinand (1840).
White silicious sand	360	400
Carbonate of potash	..	160
Carbonate of soda	150	
Carbonate of lime	84	
Borax	..	20
Red oxide of lead	..	20
Peroxide of manganese	..	1
Arsenic	6	

Bontemps has observed that crown-glass is less liable to exfoliate under the influence of damp, by introducing into its composition borax with carbonate of soda, not in excess, however, or else the same inconvenience is produced.

Lastly, *Faraday*, *Dutirou*, and several other *savans* and practical men, have made many researches on very heavy kinds of flint and very refractive kinds of crown-glass, with a view of making the relations between the various colours of their respective spectra the same; but these researches, although very interesting in the optics of astronomical telescopes, are of little use to photographic opticians, in whose hands ordinary crown-glass, united with light flint, produces excellent results. Recourse is rarely had to the heavy kinds of flint, which generally present a yellowish colouration—a colour which, above all, is objectionable for photographic use.

The grinding Tools fitted for working the surfaces of Lenses.—The lenses being brought to a shape approximate to that which they are to have, either by casting, or by grinding with wet sand in convex or concave tools of cast-iron, are now to be brought to the form calculated by theory or indicated by practice. For this purpose they are ground with fine emery, in spherical tools of brass or iron, with given radii of curvature, a little larger than the lens to be ground, otherwise the surface of the outer part of the lens would not be spherical.

A sufficient thickness is given to these tools to enable them to resist flexion. When small, they are cast in a single piece of a sufficient thickness; but when they are large—over six or eight inches in diameter, for example—they are made only half an inch thick, and cemented solidly to a thick stone, or to a second tool of cast iron, or some such thing.*

To make the tool, the iron is first cast in a mould made from a model in wood and is then finished in a lathe.

It is necessary to give to the tools the radii of curvature which the surfaces of the lens must have. For this purpose, by means of a beam-compass, an arc of a circle, double the diameter of the tool, is drawn on a plate of copper, made very flat by hammering, and followed up carefully with a file, so as to have an exact shape. Two of them are made, the one concave, the other convex; then, after having fixed one on the table, the other is rubbed against it with emery. The two gauges are thus rubbed one upon the other, so as to give them accurately the curvature which they must have.

These gauges are applied against the tools (the one convex, the other concave) whilst they are being worked in the lathe; an operation which gives them, approximately, the radius of curvature which they ought to have. The tools, thus finished, are rubbed the one in the other with emery, until they touch each other at all parts, by which means they are made spherical. It is necessary to have two tools,—the one convex, the other concave,—because during the process of grinding the lens, the tool with which this is done loses its shape, and then requires to be rubbed with the other in order to restore to it its primitive curvature.

The roughly fashioned lens is fixed by means of soft pitch, spread out in separate drops on one of its surfaces, to a plate of brass, rounded and worked in the lathe in such a way as that the glass adapts itself to it as closely as possible. For this end

* The method adopted by Mr. Ross is not to cement them down on a thick stone, but *to support the entire* tool by means of iron ribs cast to it.

the glass and the plate should be previously warmed. The plate holds the glass, and prevents its yielding under the pressure of the hand. Before pursuing these operations, the edge of the glass is ground down so as to make it quite circular, which is done by fixing it in the lathe and turning it true with the point of a diamond or other hard stone.

It is from this moment that the most delicate operations in the manufacture of the lens begin.

Smoothing and polishing of the surface of Lenses.—The tool, either concave or convex (according as the face of the lens is to be convex or concave), being fixed in a very solid block, receives a little moistened fine emery. The lens, fixed on its plate, is taken in the right hand (there is often attached to the plate a handle to render its management more easy), and moved about in the tool with more or less pressure. The glass is moved about in the tool five or six times in a circle, and two or three times in different directions. Great care must be taken, never to go beyond the edge of the tool (which, for this object, should be a little larger than the glass) and, to keep the emery always damp. At the end of a period varying with the extent of the surface to be worked, and when the glass touches closely at all points of the surface of the tool, the emery is changed for finer and finer kinds, and the smoothing is continued until all the lines and marks have quite disappeared from the surface of the glass. It is necessary, from time to time, to retouch the tool (supposing it to be concave) with the convex tool, so as to preserve its curvature. It is especially when the work is advanced that this retouching becomes often necessary. Lastly, after the emery, very fine pumice-stone is used, which renders the grain still finer, and begins the polishing. At this stage the lens is detached from its plate with the point of a knife, and the other surface is worked in the same manner. Before commencing, it is necessary to examine, by means of the lathe, if the lens be well centred on its plate, or at least approximately so. This is done by looking at the

margin of the lens, which should then have throughout the same thickness.

The lens, after the grinding, has curvatures really spherical; and now commences the difficult operation of polishing, for which extremely skilful workmen are necessary, the polishing very often altering the spherical surfaces of the lens.

There are several methods of polishing, a succinct idea of which is here given. A melted mixture of equal parts of pitch and resin is passed through a piece of linen. The tool is gently heated, and the preceding mixture (somewhat cooled so that it may have lost its previous fluidity) is spread over it in sufficient quantity to cover it to a thickness of three or four millimètres. The resinous mixture is spread in a uniform layer by means of the other tool, which for this purpose ought to be very cold and thoroughly clean. The first tool is then plunged into cold water to harden the resinous mixture, a little very fine rouge is spread over its surface, and the lens carefully polished by proceeding in the same way as for the smoothing previously described, until the operation is completed. It is necessary to take care that the glass do not get hot, and to exert a uniform pressure with the hand over all the surface of the lens, otherwise certain parts of the surface will be polished before the others, and the surface thus lose its sphericity. To avoid this defect, some opticians add round the lens, which they fix in the resinous mixture on the block, segments of the same radius of curvature, so that the lens occupies the centre, and the intervals between the segments absorb the excess of the rouge. In this way a surface very nearly spherical is obtained, but the operation is a more tedious one.*

In following the preceding method (without additional segments), it is necessary to trace in the cement some furrows at a distance from each other of half an inch, about a line broad, and crossing each other perpendicularly. All the

* The author has seen this method practised at Mr. Ross's establishment in London.

superfluous parts of the rouge collect in these, as well as the fragments of cement which become accidentally detached.

It is also necessary, as in the smoothing, to preserve the curvature of the tool by applying from time to time the other tool to it, and rubbing them together with a little fine rouge, which is then removed with water.

Another method of polishing consists in spreading on the tool a sheet of damp paper, which is made to adhere by applying the other tool to it, and which is lightly rubbed with moist rouge. The lens is then polished in this paper tool. It is stated that German opticians employ, instead of paper, fine cloth, and that they thus obtain a very fine polish.

Whatever method of polishing be employed, the lens still has not an absolutely spherical surface, unless a series of precautions be taken, which renders the lens of a very high price, and which is only adopted by opticians of the highest rank, for the polishing of astronomical objectives.

The spherical curvature of the lens, polished as has been just described, is, however, sufficiently correct for the purposes of photography, where images have not to be magnified by powerful eye-pieces, like those formed in the focus of telescopes.

Lastly, to avoid the flexion of the glass during the smoothing and polishing, the margin of the lens is always left of a certain thickness.

Lenses with convex surfaces are the easiest to work; convergent and divergent meniscus lenses are much more difficult to manipulate. Such lenses are even difficult to obtain of correct surfaces; for example, the three lenses constituting the *wide-angled lens of Dallmeyer*, those constituting the *globe-lens of Harrison*, and the *doublet of Ross*, objectives of which we shall shortly speak.

Centering and mounting of Lenses.—When the centres of the two surfaces of the lens are in the same right line, perpendicular to the plane of the circumference of the lens,

the lens is centered, and has the same thickness at all parts of its margin. When less than two inches in diameter, the lens is put in the lathe and fixed in it with mastic as solidly and as centrally as possible. On making it revolve, and observing in its two faces the reflected image of a distant candle-flame, the two images produced by the surfaces should not be displaced from each other. If the centering is imperfect, one or both of the images describes a circle. It then becomes necessary to move the lens until the centering is perfect, that is, until the images remain motionless, and then to grind with copper and emery the margin of the lens.

If the lens be more than two inches in diameter, it is again placed in the lathe on a chuck capable of universal adjustment. A peculiar construction of callipers, the legs of which are of unequal length, is then fixed to the bench of the lathe, in such a way that the lens near its margin may run between the two shortest legs, the two others being provided with a spring, which tends to separate them from each other. If now the lens be revolved, the extremities of the callipers separate or approach, if the lens is not centered. The chuck is then re-adjusted until the callipers record the uniform thickness of the lens at its outer parts. In this position the lens is made circular, by giving it a rapid rotary movement, and by rubbing it gently at the margin, without shocks or jolts, which would displace it. By such means the lens is centered.

We operate in the same manner for convergent and divergent lenses, and as most usually a convergent lens is combined with a divergent lens in the same ring (called a *cell*), we give them the same diameter, taking care that the edges are at right angles to the plane of the circumference, that is, parallel to the axis of the lenses.

The two lenses are often cemented together, and must then present a common surface. To effect this, they are warmed, a little *Canada balsam* is poured into the concave surface, and then, after applying to this the convex surface, the two lenses

are pressed together, so as to force out the excess of the liquid. When cooled, the lenses hold firmly together (for they cannot be separated without heat), and form but a single one.

Frequently also, when the two lenses have not a common surface, three small pieces of tin-foil are introduced at equal distances asunder, between their margins, so as to separate them; or a brass ring is employed for this purpose. The objective which photographers call the "*the double combination*" offers an example of these two ways of mounting lenses; those in front, which look towards the object to be reproduced, are cemented together, while the two behind are separated in their common mounting by a ring.

When the lens is fixed in its brass ring, so that it cannot be taken out without raising the bent edge of the brass with a knife, it is said to be *set*. Most usually, it is kept in place by a second ring, which can easily be unscrewed.

SECTION III.—*Law of conjugate Foci, and the magnitude of Images at the focus of Lenses.*

In this chapter we treat of the course of luminous rays through lenses. But, in order not to uselessly complicate this study, we suppose two conditions, from which we shall free ourselves presently, but of which the reader ought not to lose sight. The first is, that incident rays are composed of simple light (for, as we have already seen, the refraction of a ray of white light is always accompanied by its decomposition). The second is, that lenses have, at their central part, an extremely slight thickness, or even none at all*; or, in other

* That, at least, is the condition commonly set forth in treatises on physics. But it is a very erroneous one when applied to meniscus lenses, of which the radii of curvature are very short and the diameter is considerable, although the thickness of such lenses is slight. To illustrate this, fig. 19 represents a convergent meniscus, of which C R and C′ R′ are the radii of

words, that the radii of curvature of the faces are very great relatively to their diameter.

Assimilation of Lenses to Prisms.—In studying the course of luminous rays through lenses, it is always supposed, which is, moreover, true, that the infinitely small portion of the lens struck by the ray may be replaced by a tangent plane.

A convergent lens may thus be considered as formed of prisms united at the base, and a divergent lens of prisms united at the summit. Thus, a bi-convex lens, A (fig. 20), may be assimilated to two prisms (B) joined at the base; and a divergent lens (C), to two prisms (D) united at the summit. This explains how it is that the former (and all convergent lenses, in general) causes rays, *r r*, incident upon it, to meet in *f*, and that the latter causes them to separate along *r′*; since we know that prisms deviate towards their base rays which traverse them.

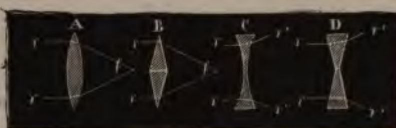


Fig. 20.

To find geometrically the course of a luminous ray, R D, (fig. 21), falling parallel to the axis C C, on a lens L M, (bi-convex for example, but the thickness of which we shall neglect), take the radius of curvature, D C′, of the face M, and

curvature. Now, if C C′ is small the thickness will be small, and could be regarded as nothing if the lens were bi-convex. However, on applying to this lens the ordinary formulæ which determine the focal distance, the expression of its aberration, &c., a relatively considerable error comes out. This is why the definition, "no thickness," is erroneous. It is necessary that the versed sine *a b* of the radius of curvature may be treated as nothing in relation to this radius, particularly in calculations relating to aberrations.

Fig. 19.

the radius of curvature, C E, of the face N, the two making with the axis C C′ equal angles. To these radii of curvature

Fig. 21.

draw the tangents D A and E A. We have, then, no longer to consider the lens, but the prism A. Now, the angle A being infinitely small (since we regard the lens as very thin), the deviation which it produces on the ray which falls normally to its bisector A B, is equal to $(n-1)$ A. The emergent ray E R′ will then cut the axis in a point *f*.

If in place of the incident ray R D any other is taken (but always parallel to the axis) more or less removed from the centre of the lens, it is found, on converting the angle A into figures, that all the emergent rays cut the axis of the lens at the same point, *f*, which constitutes its *principal focus*.

Calculation of the focal length of Lenses; Principal Focus and conjugate Focus.—Let A B be the spherical

Fig. 22.

surface, infinitely small, of a medium more refractive on the right of A B than on the left; let D be a radiating point, *emitting* an incident ray, D A. Join the centre of curvature,

C, of the surface A B to the points A and D; the *axis* will be D C, and A C the normal, to which the refracted ray will approach, cutting the axis in f'. Let us determine the relation of B D to B f'.

From the point C let fall on the incident ray and on the refracted ray the perpendiculars C H, C I, and consider A B as a straight line; which may be done, it having been considered as an arc infinitely small. The right-angled triangles D A B, D H C, are similar, the angle at D being common, and give the proportion D C : D A :: C H : A B, and by supposing (the angle f' being very small) D A = D B = p (*the distance of the radiating point from the spherical surface*), and B C being equal to R (*the radius of curvature of the spherical surface*) D C = p + R, and this proportion may be written $p + \mathrm{R} : p ::$ C H : A B.

The similar triangles f' I C, f' A B (being rectangular, and f' common), give, f' C : f' B :: I C : A B. Now, f' A = f' B (f' being, like D, very small), f' B = p' (*focal distance of* A B), therefore $p' - \mathrm{R} : p' ::$ I C : A B.

Dividing the two proportions, term by term, we get $\frac{p + \mathrm{R}}{p' - \mathrm{R}} : \frac{p}{p'} :: \frac{\mathrm{C\,H}}{\mathrm{C\,I}} : 1$. C H and C I are the sines of the angle of incidence and the angle of refraction; their ratio is therefore the index of refraction n, therefore $\frac{p + \mathrm{R}}{p' - \mathrm{R}} = \frac{p\,n}{v'}$; from which we get

$$\frac{1}{p} + \frac{n}{p'} = \frac{n-1}{\mathrm{R}} \quad .\ .\ .\ .\ (1).$$

Now, in a similar way it may be shown that if the ray is refracted behind the incident ray, the formula becomes

$$\frac{1}{p} - \frac{n}{p'} = \frac{n-1}{\mathrm{R}}.$$

We see, therefore, that whatever may be the incidence of the ray D A, *for we have* chosen it arbitrarily, f' B or p'

remains constant, since the preceding equation does not mention the incidence; *therefore all rays emitted from a radiating point to the infinitely small spherical surface of a medium are refracted to a common point, called the focus.*

We have supposed the incident ray D A oblique to the axis D C, but if we had supposed it parallel to the axis, as D′ A, we should get for the refracted ray A P instead of A F, and the point P determines the *principal focus* of the medium.

In this case, p' (B P) $= \dfrac{n\,\mathrm{R}}{n-1} \ldots .$ (2).

Let us take, now, the case of a lens (fig. 23), which we shall

Fig. 23.

suppose bi-convex, with equal curvatures, sufficiently thin for its thickness to be neglected, and with very small aperture, precisely as we made it for the preceding case. The letters from fig. 22 indicate the same things. Let A B, A′ B′ be the two surfaces of the lens; C, C′ the centres of curvature; C A, C′ A′ the radii of curvature R, R′; D f the axis; D A an incident ray coming from a point, D, situated on the axis: the refracted ray will be, as in the preceding case, A f, and we shall have, supposing the medium to the right of A B to be of indefinite extent,

$$(1) \ldots . \frac{1}{p} + \frac{n}{p'} = \frac{n-1}{\mathrm{R}}.$$

But the refracted ray meets the face A′ B′ in A′ and cuts *the axis* in f'. Let us now suppose the medium to be of in-

definite extent to the left of A′ B′; f' as the radiating point; f' A′ an incident ray; A′ A the refracted ray: its prolongation will cut the axis in f. We should thus have $\frac{1}{f' \mathrm{B}'} - \frac{n}{\mathrm{B}' f} = \frac{n-1}{\mathrm{R}'}$. Let f' B′ $= p'$, and B′ $f = p$; and this proportion becomes

$$(2) \ldots\ldots \frac{1}{p'} - \frac{n}{p} = \frac{n-1}{\mathrm{R}'}.$$

Neglecting B B′, which we regard by hypothesis as infinitely small, and adding the two equations together we get

$$(3) \ldots\ldots \frac{1}{p} + \frac{1}{p'} = \frac{n-1}{\mathrm{R}} + \frac{n-1}{\mathrm{R}'} = \frac{(n-1)(\mathrm{R}+\mathrm{R}')}{\mathrm{R}\,\mathrm{R}'}.$$

It is plain that p and p'—that is to say, *the distance of the radiating point from the lens, and the focal distance* of it—do not depend at all on the incidence of the ray D A, but only on the radii of curvature R and R′ of the lens, and the index of refraction of which it is formed. Which was to be demonstrated.

If the incident ray D A is parallel to the axis, p is infinite, and p' represents the *principal focal distance* of the lens, in this case p' or f becomes

$$f = \frac{\mathrm{R}\,\mathrm{R}'}{(n-1)(\mathrm{R}+\mathrm{R}')}.$$

Formulæ determining the principal focal lengths of Lenses for Rays parallel to the Axis.—Knowing the index of refraction n of the material of which the lens is formed, and its radii of curvature R and R′, its principal focal distance f is given for the different kinds of lenses by the following formulæ. We have to remark, however, that the value of f is only approximate, because we take no account in them of the thickness of the lens. For a closer approximation, see the *Treatise on the Reflection and Refraction of Light*, by Henry Coddington, Cambridge, 1829, pages 94 *et seq.*

N.B.—The focal length f is reckoned from the optical centre of the lens.—*(See p. 36.)*

(1) *Bi-convex lens* (R > R′ or R′ > R).

$$f = \frac{R R'}{(n - 1)(R + R')}.$$

(2) *Equi-convex lens* (R = R′).

$$f = \frac{R}{2(n - 1)}.$$

(3) *Plano-convex lens.*

$$f = \frac{R}{(n - 1)}.$$

(4) *Convergent meniscus* (R′ > R).

$$f = \frac{-R R'}{(n - 1)(R - R')}.$$

(5) *Bi-concave lens* (R > R′) or R′ > R).

$$f = \frac{-R R'}{(n - 1)(R + R')}.$$

(6) *Equi-concave lens* (R = R′).

$$f = \frac{-R}{2(n - 1)}.$$

(7) *Plano-concave lens.*

$$f = \frac{-R}{(n - 1)}.$$

(8) *Divergent meniscus* (R > R′).

$$f = \frac{-R R'}{(n - 1)(R - R')}.$$

Examples of these calculations.—1. What is the focal length of a bi-convex lens, of which the radii of curvature are respectively 6 mètres and 1 mètre, and the index of refraction 1·5?

Formula (1) gives $f = \frac{6 \times 1}{(1 \cdot 5 - 1)(6 + 1)} = \frac{6}{3 \cdot 5} = 1 \cdot 714$ mètres.

2. What would be the focal length of a convergent menis-

cus, having the same radii of curvature and index of refraction as in the preceding example?

It is necessary to take [formula 4] $R' > R$; therefore $R' = 6$, and $R = 1$. If not, instead of a convergent meniscus, we should have a divergent one.—(See the next example.)

$$f = \frac{-1 \times 6}{(1\cdot5 - 1)\ (1 - 6)} = \frac{-6}{-2\cdot5} = 2\cdot4 \text{ mètres.}$$

3. What would be the focal length of a *divergent* meniscus with the same radii of curvature and the same index of refraction as before?

It is necessary to take (formula 8) $R > R'$; therefore $R = 6$, and $R' = 1$; and we have—

$$f = \frac{-6 \times 1}{(1\cdot5 - 1)\ (6 - 1)} = \frac{-6}{2\cdot5} = -2\cdot4 \text{ mètres.}$$

4. I wish to have made by an optician a bi-convex lens of 1·714 mètres focal distance, the two radii of curvature being *to each other* as 1 to 6. What will be the lengths of the radii of curvature, the index of refraction being 1·5?

Since one of the radii of curvature is 6 times as long as the other, $R' = 6\ R$.

In formula (1) we replace f by its given value (1·714 mètres), and R' by its value 6 R, and we shall get

$$1\cdot714 \text{ mètres} = \frac{R \times 6R}{0\cdot5 \times 7R} = \frac{6R}{3\cdot5};$$

whence $6R$ or $R' = 1\cdot714 \text{ mètres} \times 3\cdot5 = 6$ mètres,

and $R = 1$ mètre.

5. I possess a bi-convex lens, and I wish to know the index of refraction of the material of which it is formed. I have measured its focal length, which is 1·714 mètres, and its two radii of curvature, which are respectively 1 mètre and 6 mètres. What is this index? (formula 1),

$$1\cdot714 = \frac{6 \times 1}{(n - 1)\ (1 + 6)} = \frac{6}{7n - 7};$$

whence $(7n - 7)\ 1\cdot714 = 6$; whence $n = \frac{3}{2}$ or $1\cdot5$.

It is seen, therefore, that these formulæ always enable n, R and R', or f to be found, two of the three elements being known. These formulæ are therefore in frequent use.

Focal length of Lenses.*—Let us suppose, first, the most simple case, namely, that of luminous rays r (fig. 24) emanating from a point infinitely distant—of a star, for example—and falling parallel to the axis of a convergent lens A. In this case the emergent rays all converge towards a single point, f, in the axis, which has been named the *principal focus* of the lens, and at which an image of the point is formed.

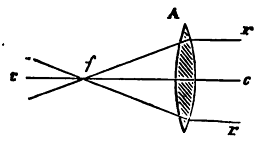


Fig. 24.

Conversely, a luminous point f (fig. 25)—a candle, for example—placed in the principal focus of a convergent lens A, emits divergent rays which, after having traversed the lens, all emerge from it along r, parallel to each other and to the axis.

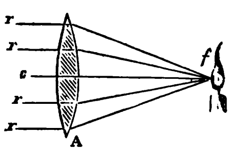


Fig. 25.

The principal focus of a convergent lens is therefore always very easy to determine approximately by experiment. It is sufficient for this to present the lens to the solar rays in such a manner that these fall perpendicularly upon it, and to measure the distance which separates the centre of the lens from the sharpest image of the sun which is formed at its focus.—(See p. 65). There is, however, a slight error which results from the thickness of the lens, particularly if it is a convergent meniscus.

Instead of a radiating point situated at infinity, let us take a point nearer to the lens, but situated in its axis. In this case, the rays emitted by the luminous point are no longer

* This paragraph is only an elementary enunciation of that which has been demonstrated geometrically in the preceding paragraphs.

parallel; they diverge, and fall divergently on the lens, and their focus is formed so much the farther beyond the lens the more the point approaches it. If the radiating point is at a distance from the lens equal to double its principal focal length, then its image is formed at a distance precisely equal behind the lens. The more it approaches, the farther off its image is formed; and there comes at last a moment —that at which the radiating point is at a distance from the lens equal to its principal focal length—when the rays emerge parallel to each other, and no longer form any image at all.

Divergent lenses form no images at all, whatever the distance of the radiating point. Hence it is (fig. 26) that the rays *r r*, parallel to the axis, A *f*, of a lens A, emerge along *r′* divergent. There is therefore formed no real image behind the lens. If we prolong the rays *r′* until they meet the axis, as shown in the figure, A *f* will be the principal focal length of the lens A.

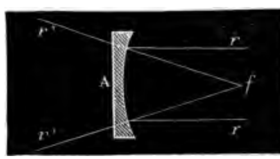


Fig. 26.

The same relation which exists between the variable focal length of convergent lenses, and the distance of the radiating point, exists for divergent lenses; only that, instead of a focus forming behind the lens, none at all is really formed, but one is said to be formed *virtually*.

Just as the deviation of a luminous ray produced by a prism depends on the angle of the prism, and the index of the material of which it is made, so the principal focal distance of a lens depends on the radii of curvature of the spherical surfaces which form it and on its index of refraction. It is clear, in fact, that the shorter the radii of curvature are the shorter will be the focal length. Also, of two lenses with equal curvatures, that which is formed of the most highly refractive material will have the shortest focal length.—(See p. 67.)

The focal Plane.—If, instead of a single luminous point situated in the axis of the lens, we consider an object, C D (fig. 27), of a certain size, we find sensibly the same results if the extent of the object is not very great. For let us consider a point D in this object (which we shall suppose situated at infinity) sending to the convergent lens A B a pencil of rays

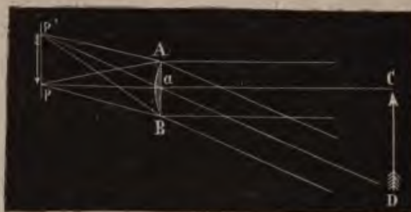


Fig. 27.

oblique to the axis a C; its image will be formed at p', sensibly in the same plane (perpendicular to the axis a C) as the focus p of the rays parallel to the axis of the lens and coming from the point C. The plane $p\,p'$ is called the *focal plane.*

It is seen, therefore, that the image $p\,p'$ is formed inverted behind the lens, and that its size evidently depends upon the size of C D, and also upon the distance, a C, of the object from the lens, and on the focal length of the latter; since in the two similar triangles $p\,p'\,a$ and C D a there is the proportion—

$$\mathrm{C\,D} : pp' :: \mathrm{C}a : ap.$$

The shorter, therefore, the focal length of a convergent lens (the object C D remaining at a constant distance), the smaller will be the image of the object. The farther the object is removed from the lens A B (its focal length being given), the smaller, again, will be the image of the object.

Between the focal length of a lens, the distance of the object from the lens, and the size of the image, there are, therefore, geometrical ratios, which we must further study. The law which connects these distances is called the *law of conjugate foci.*

Experimental determination of the absolute focal

length of Lenses.—We have given at page 51 formulæ by the aid of which the principal focal length of a lens was easily determined, and at page 52 an experimental process for the same purpose; but neither the one nor the other of these methods is sufficiently exact if it be applied to a system of lenses having a common axis—for example, to photographic objectives. In this case the following method is applied:—

Let A, B (fig. 28) be objects widely separated, situated in the horizon, C the objective screwed on to a camera placed on a well-levelled table. On bringing them to a focus on the ground-glass, we find that the objects D and E form the limit of the image on the ground-glass. D C E is the angle included by the lens. Draw on the middle of the ground-glass a vertical right line, and turn the camera until the point E falls on this line. With a pencil pressed against the side of the camera draw

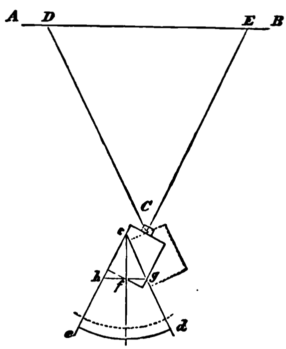


Fig. 28.

the right line *c e*. Turn the camera towards the point D until this point falls on the line traced on the ground-glass. Draw the right line *c d* in the same way as *c e* was done. If this line does not cut *c e*, prolong it until it does. It is clear that the angle *e c d* is equal to D C E. Therefore, by placing the centre of a protractor at *c*, the number of degrees, *e d*, is read off, that is, the angle included by the lens.

Its *absolute* focal length is thus obtained:—Measure on the ground-glass the distance of the points D E with a compass, and take the half of them. Bisect the angle *e c d* by a straight line *c f*, against which place a square rule. Carry the half-distance D E (measured on the ground-glass) on the square rule, and make *f g* equal to this half-distance and perpendicular *to c f. Then f c will* be the true focal length of the

objective, which, once known, permits the size of images to be calculated.—(Grubb, *British Journal of Photography.*)

Determination of the conjugate Focus and of the size of the Image.—First, let us recall this fact: that if in a well-darkened chamber (fig. 2, page 6) we make a small aperture, external objects will be represented on a white screen placed behind this aperture. *The greater the distance of these objects, the smaller their image is; but this image can be enlarged or diminished by withdrawing or advancing the screen which receives it.* If, at the aperture, we place a convergent lens, we shall observe that there is a place behind the lens where the image is the best defined: on advancing or withdrawing the screen, the image will lose its primitive sharpness.

If the fixed object, which, in our figure (2, page 6) is represented by a church, is replaced by a moving figure—by a man who is walking, for example—we can prove that, if the man moves away, the image on the screen, to be the sharpest possible, approaches the lens, and diminishes in size; and that, conversely, if the man approaches, the focus moves off from the lens, and the image increases in size.

Now, there are, between the focal length of the lens, the size of the image, and the distance of the object from the lens, very simple ratios, by the aid of which, knowing two of the ratios, the third can always be found. Let f be the principal focal length of the lens (or system of combined lenses), p the distance of the object from the lens, p' the focal length of the lens at which the image is sharply defined. We have the ratio:—

$$\frac{1}{f} = \frac{1}{p} + \frac{1}{p'}.$$

If the objective has a focal length of 24 centimètres, the distance of the object from the lens being 400 centimètres, we shall have for the distance p', at which the image is represented with clearness on the ground-glass:

$$\frac{1}{24} = \frac{1}{400} + \frac{1}{p'}, \text{ or } 400 - 24 = \frac{24 \times 400}{p'};$$

whence $p' = 25{\cdot}5$ centimètres. The focal distance will therefore, in this case, be elongated 1·5 centimètres beyond the principal focus.

The ratio of the size of the image to that of the object will be as $p' : p$, or as 25·5 to 400; that is, the image will be approximately $\frac{1}{16}$ of the size of the object.

It is therefore always easy, knowing the focal length of the lens we make use of, the dimension of the object and its distance from the lens, to calculate exactly the dimension of the image. Or, changing the problem, and wishing with a given objective to obtain an image of definite size, to find out at what distance it will be necessary for the object to be placed. But, to save our readers this labour, we extract from the excellent pamphlet of M. Sécretan, entitled, "*De la distance focale des systèmes optiques convergents*," the following tables (pp. 60, 61, 62), with the explanation of the mode of using them.*

The first vertical column contains the focal lengths of the lenses, increasing by 5 centimètres, from 10 to 100 centimètres; for intermediate focal lengths, the results can be interpolated or rather calculated by the rules already given (see page 58). The second vertical column, which has at the top the fractional number $\frac{1}{1}$, gives for a full-sized image, and for the focal length of each lens opposite to it in the first column, two numbers: the first is the distance of the object from the lens; the second that of the ground-glass from the lens. The third vertical column gives the same distances, but for a half-sized image; the fourth column gives them for the ratio $\frac{1}{3}$, and so on.

* Opticians, in their catalogues, generally give, in place of the true focal length of their objectives, that measured from the face of the lens which is directed towards the ground-glass. There is thence no very sensible error for the simple landscape objectives; but for all others it is necessary, either to measure the focal length in the way we have indicated above, or else to add to the *figures* given by opticians half the length of the tube *in which the objectives* are mounted.

	1/1	1/2	1/3	1/4	1/5	1/6	1/7	1/8	1/9
0·10	0·20	0·30	0·40	0·50	0·60	0·70	0·80	0·90	1·00
	0·20	0·15	0·13	0·13	0·12	0·12	0·11	0·11	0·11
0·15	0·30	0·45	0·60	0·75	0·90	1·05	1·20	1·35	1·50
	0·30	0·23	0·20	0·19	0·18	0·18	0·17	0·17	0·17
0·20	0·40	0·60	0·80	1·00	1·20	1·40	1·60	1·80	2·00
	0·40	0·30	0·27	0·25	0·24	0·23	0·23	0·23	0·22
0·25	0·50	0·75	1·00	1·25	1·50	1·75	2·00	2·25	3·50
	0·50	0·38	0·33	0·31	0·30	0·29	2·29	0·28	0·28
0·30	0·60	0·90	1·20	1·50	1·80	2·10	2·40	2·70	2·00
	0·60	0·45	0·40	0·38	0·36	0·35	0·34	0·34	0·33
0·35	0·70	1·05	1·40	1·75	2·10	2·45	2·80	3·15	3·50
	0·70	0·53	0·47	0·44	0·42	0·41	0·40	0·39	0·39
0·40	0·80	1·20	1·60	2·00	2·40	2·80	3·20	3·60	4·00
	0·80	0·60	0·53	0·50	0·48	0·47	6·40	0·45	0·44
0·45	0·90	1·35	1·80	2·25	2·70	3·15	3·60	4·05	4·50
	0·90	0·68	0·60	0·56	0·54	0·53	0·51	0·51	0·50
0·50	1·00	1·50	2·00	2·50	3·00	3·50	4·00	4·50	5·00
	1·00	0·75	0·67	0·63	0·60	0·58	0·57	0·56	0·55
0·55	1·10	1·65	2·20	2·75	3·30	3·85	4·40	4·95	5·50
	1·10	0·83	0·73	0·69	0·66	0·44	0·63	0·62	0·61
0·60	1·20	1·80	2·40	3·00	3·60	4·20	4·80	5·40	6·00
	1·20	0·90	0·80	0·75	0·72	0·70	0·69	0·68	0·66
0·65	1·30	1·95	2·60	3·25	3·90	4·55	5·20	5·85	6·50
	1·30	0·98	0·87	0·81	0·78	0·76	0·74	0·73	0·72
0·70	1·40	2·10	2·80	3·50	4·20	4·90	5·60	6·30	7·00
	1·40	1·05	0·93	0·87	0·84	0·82	0·80	0·79	0·77
0·75	1·50	2·25	3·00	3·75	4·50	5·25	6·00	6·75	7·50
	1·50	1·13	1·00	0·94	0·90	0·88	0·86	0·84	0·83
0·80	1·60	2·40	3·20	4·00	4·80	5·60	6·40	7·20	8·00
	1·60	1·20	1·07	1·00	0·96	0·93	0·91	0·90	0·88
0·85	1·70	2·55	3·40	4·25	5·10	5·95	6·80	7·65	8·50
	1·70	1·28	1·13	1·06	1·02	0·99	0·97	0·96	0·94
0·90	1·80	2·70	3·60	4·50	5·40	6·30	7·20	8·10	9·00
	1·80	1·35	1·20	1·12	1·08	1·05	1·03	1·01	0·99
0·95	1·90	2·85	3·80	4·75	5·70	6·65	7·60	8·55	9·50
	1·90	1·43	1·27	1·19	1·14	1·11	1·09	1·07	1·05
1·00	2·00	3·00	4·00	5·00	6·00	7·00	8·00	9·00	10·00
	2·00	1·50	1·33	1·25	1·20	1·17	1·14	1·15	1·10

	1/10	1/15	1/20	1/25	1/30	1/40	1/50	1/60	1/70
0·10	1·10	1·60	2·10	2·60	3·10	4·10	5·10	6·10	7·10
	0·11	0·11	0·11	0·10	0·10	0·10	0·10	0·10	0·10
0·15	1·65	2·40	3·15	3·90	4·65	6·15	7·65	9·15	10·65
	0·17	0·16	0·16	0·16	0·16	0·15	0·15	0·15	0·15
0·20	2·20	3·20	4·20	5·20	6·20	8·20	10·20	12·20	14·20
	0·22	0·21	0·21	0·21	0·21	0·21	0·20	0·20	0·20
0·25	2·75	4·00	5·25	6·50	7·75	10·25	12·75	15·25	17·75
	0·28	0·27	0·26	0·26	0·26	0·26	0·26	0·25	0·25
0·30	3·30	4·80	6·30	7·80	9·30	12·30	15·30	18·30	21·30
	0·33	0·32	0·32	0·31	0·31	0·31	0·31	0·31	0·30
0·35	3·85	5·60	7·35	9·10	10·85	14·35	17·85	21·35	24·85
	0·39	0·37	0·37	0·36	0·36	0·36	0·36	0·36	0·36
0·40	4·40	6·40	8·40	10·40	12·40	16·40	20·40	24·40	28·40
	0·44	0·43	0·42	0·42	0·41	0·41	0·41	0·41	0·41
0·45	4·95	7·20	9·45	11·70	13·95	18·45	22·95	27·45	31·95
	0·50	0·48	0·47	0·47	0·47	0·46	0·46	0·46	0·46
0·50	5·50	8·00	10·50	13·00	15·50	20·50	25·50	30·50	35·50
	0·55	0·53	0·53	0·52	0·52	0·51	0·51	0·51	0·51
0.55	6·05	8·80	11·55	14·30	17·05	22·55	28·05	33·55	39·05
	0·61	0·59	0·58	0·57	0·57	0·56	0·56	0·56	0·56
0·60	6·60	9·60	12·60	15·60	18·60	24·60	30·60	36·60	42·60
	0·66	0·64	0·63	0·62	0·62	0·62	0·61	0·61	0·61
0·65	7·15	10·40	13·65	16·90	20·15	26·65	33·15	39·65	46·15
	0·72	0·69	0·68	0·68	0·67	0·67	0·66	0·66	0·66
0·70	7·70	11·20	14·70	18·20	21·70	28·70	35·70	42·70	49·70
	0·77	0·75	0·74	0·73	0·72	0·72	0·71	0·71	0·71
0·75	8·25	12·00	15·75	19·50	23·25	30·75	38·25	45·75	53·25
	0·83	0·80	0·79	0·78	0·77	0·77	0·77	0·76	0·76
0·80	8·80	12·80	16·80	20·80	24·80	32·80	40·80	48·80	56·80
	0·88	0·85	0·84	0·83	0·83	0·82	0·82	0·81	0·81
0·85	9·35	13·60	17·85	22·10	26·35	34·85	43·35	51·85	60·35
	0·94	0·91	0·89	0·88	0·88	0·87	0·87	0·86	0·86
0·90	9·90	14·40	18·90	23·40	27·90	36·90	45·90	54·90	63·90
	0·99	0·96	0·95	0·94	0·93	0·92	0·92	0·92	0·91
0·95	10·45	15·20	19·95	24·70	29·45	38·95	48·45	57·95	67·45
	1·05	1·01	1·00	0·99	0·98	0·97	0·97	0·97	0·97
1·00	11·00	16·00	21·00	26·00	31·00	41·00	51·00	61·00	71·00
	1·10	1·07	1·05	1·04	1·03	1·03	1·02	1·02	1·01

	1/80	1/90	1/100	1/120	1/140	1/160	1/180	1/200
0·10	8·10	9·10	10·10	12·10	14·10	16·10	18·10	20·10
	0·10	0·10	0·10	0·10	0·10	0·10	0·10	0·10
0·15	12·15	13·65	15·15	18·15	21·15	24·15	27·15	30·15
	0·15	0·15	0·15	0·15	0·15	0·15	0·15	0·15
0·20	16·20	18·20	20·20	24·20	28·20	32·20	36·20	40·20
	0·20	0·20	0·20	0·20	0·20	0·20	0·20	0·20
0·25	20·25	22·75	25·25	30·25	35·25	40·25	45·25	50·25
	0·25	0·25	0·25	0·25	0·25	0·25	0·25	0·25
0·30	24·30	27·30	30·30	36·30	42·30	48·30	54·30	60·30
	0·30	0·30	0·30	0·30	0·30	0·30	0·30	0·30
0·35	28·35	31·85	35·35	42·35	49·35	56·35	63·35	70·35
	0·35	0·35	0·35	0·35	0·35	0·35	0·35	0·35
0·40	32·40	36·40	40·40	48·40	56·40	64·40	72·40	80·40
	0·41	0·40	0·40	0·40	0·40	0·40	0·40	0·40
0·45	36·45	40·95	45·45	54·45	63·45	72·45	81·45	90·45
	0·46	0·46	0·45	0·45	0·45	0·45	0·45	0·45
0·50	40·50	45·50	50·50	60·50	70·50	80·50	90·50	100·50
	0·51	0·51	0·51	0·50	0·50	0·50	0·50	0·50
0·55	44·56	50·05	55·55	66·55	77·55	88·55	99·55	110·55
	0·56	0·56	0·56	0·55	0·55	0·55	0·55	0·55
0·60	48·60	54·60	60·60	72·60	84·60	96·60	108·60	120·60
	0·61	0·61	0·61	0·61	0·60	0·60	0·60	0·60
0·65	52·65	59·15	65·65	78·65	91·65	104·65	117·65	130·65
	0·66	0·66	0·66	0·66	0·65	0·65	0·65	0·65
0·70	56·70	63·70	70·70	84·70	98·70	112·70	126·70	140·70
	0·71	0·71	0·71	0·71	0·71	0·70	0·70	0·70
0·75	60·75	68·25	75·75	90·75	105·75	120·75	135·75	150·75
	0·76	0·76	0·76	0·76	0·76	0·75	0·75	0·75
0·80	64·80	72·80	80·80	96·80	112·80	128·80	144·80	160·80
	0·81	0·81	0·81	0·81	0·81	0·81	0·80	0·80
0·85	68·85	77·35	85·85	102·85	119·85	136·85	153·85	170·85
	0·86	0·86	0·86	0·86	0·86	0·86	0·85	0·85
0·90	72·90	81·90	90·90	108·90	126·90	144·90	162·90	180·90
	0·91	0·91	0·91	0·91	0·91	0·91	0·91	0·90
0·95	76·95	86·45	95·95	114·95	133·95	152·95	171·95	190·95
	0·97	0·96	0·96	0·96	0·96	0·96	0·95	1·95
1·00	81·00	91·00	101·00	121·00	141·00	161·00	181·00	201·00
	1·01	1·01	1·01	1·01	1·01	1·01	1·01	1·01

Suppose that with an objective of 30 centimètres focus it is wished to make a portrait one-sixth the size.

From the number 30 in the first vertical column, the horizontal line is followed until the vertical line is reached at the top of which there is $\frac{1}{6}$; the square will be thus come to where are the two numbers 2·10 and 0·35; the first indicates that the person will have to be 2 mètres 10 centimètres from the lens, and the second shows that the ground-glass, when brought to a focus, will be about 35 centimètres from the lens. The results of the table are exact to within less than a centimètre; greater exactitude would have been useless, particularly for the number which determines the distance of the ground-glass, seeing that this is always regulated by the effective focussing. The latter quantity it is always well to know beforehand, if only to know whether the locality where we are working is large enough to effect a certain reduction of the image with an objective of a known focal length.

Thus, it is desired to know what is the smallest reduction that can be made with a focus of 40 centimètres, in a room of which the greatest length is 4 mètres. We first deduct one mètre for space for the object to be represented, and for the operator to focus on the ground-glass, and thus reduce our 4 mètres to 3.

In the horizontal line, which corresponds to the focus of 40, make up the sum of the two numbers in each square until the result is obtained which approaches nearest to, but less than, 3 mètres. We shall thus arrive at the number 2·88, furnished by the vertical column at the head of which is $\frac{1}{7}$.

Such will be the smallest sized image that could be obtained in this place with this lens.

CHAPTER V.

ABERRATIONS.

Definition of Aberrations.—We have thus far supposed the aperture of lenses to be very small relatively to their focal length, and consequently the meeting at the same point of all the rays refracted by them. But in practice lenses are most often used which have a considerable aperture, and then this result is not obtained, the rays refracted by the margin of the lens meeting at a different point in the axis from those refracted by the centre. This constitutes an *aberration*, which has been named *spherical* because it proceeds from the sphericity of the surfaces of the lens.

We have also supposed that refraction by lenses was not accompanied by dispersion; but this is not so, since for an incident white ray there are several rays refracted, and these cut the axis in different points. This is what is called *chromatic aberration.*

Again, we have admitted that the image of external objects is formed at the focus of a lens on a plane perpendicular to its axis, whereas in reality it is formed on a curved surface. This aberration is that of the *curvature of the field.*

We have supposed lenses as infinitely thin, and therefore giving images in conformity with the lines of the object. But lenses have a sensible thickness, which alters the exact form of the image at the edges. This aberration has received the name of *aberration of thickness*, or more commonly that of *distortion.*

One other aberration results from the position of the lens in relation to points situated obliquely to its axis; the two meridians of the lens having a different focal length. This aberration has received the name of *astigmation.*

SECTION I.—*Spherical Aberration.*

Spherical Aberration, lateral and longitudinai, posi-ve and negative.—The parallel rays of light r r (fig. 9), passing through the margins of a convex lens L L′, cross ach other at f', nearer to he lens than the rays r' r', hich, passing through the entre, cross each other at f. his proceeds from the cur-atures of the lens being *herical* surfaces; hence the ame *spherical aberration.*

Fig. 29.

Spherical aberration in a mple convergent lens can asily be observed by receiv-g the image of the sun at its focus. For this purpose the ns is presented to the solar rays in such a way that they ll perpendicularly to its circumference, and the place where he image is formed with sharpness is sought for by with-rawing or advancing a white paper behind the lens. (To ttain this end more easily, reduce the lens to its central part y covering it with a card having a round hole cut in it; hen remove the card.) If the lens has a very short focus,— , for instance, it is one of those lenses which are used as nagnifying-glasses,—we observe that around the best-defined mage of the sun there is an aureola, $a\,b$ (Fig. 29), of vhite light which constitutes *lateral spherical aberration.* In, act, it is at f, the focus of the rays incident on the centre of the lens, that the best-defined image is formed of objects situated at infinity (and the sun is in this condition); whilst the rays r r falling on the margins of the lens L, and having their focus f' nearer, continue their way and form a round aureola, $a\,b$, about the point f. The diameter $a\,b$ of this circle constitutes the measure, or, as it is also called, the *expression* of the lateral spherical aberration (or diameter of the circle

of aberration). The distance, $f\,f'$, (measured along the axis of the lens) which separates the focus f of the central rays from the focus f' of the extreme rays is called the *longitudinal aberration.*

The circle of *least aberration* is between f' and f. It is the smallest section it is possible to make in the cone of rays emergent from the lens.

In negative lenses the ray p', parallel to the axis $c'\,c$ of a divergent lens L N, and falling on the central part, emerges in the direction $o\ m$, which, produced, cuts the axis in $f'\,f'$, which is therefore the principal focus of this lens. A ray r, parallel to the first, falling on the margin of the lens L, emerges in the direction $n\ q$, which, produced, cuts the axis in f. Therefore the focus of the extreme rays is longer than the focus of the central rays. In this case the aberration is said to be *negative.*

Fig. 30.

Spherical Aberration varies with the aperture and index of refraction of the glass of the lens.—Since spherical aberration depends on the *sphericity* of the faces forming the lens, it is perfectly clear that the more convex these faces are—that is to say, the shorter the radii of curvature are relatively to the diameter of the lens—the more considerable are the aberrations of sphericity.

Lenses which have a short focus relatively to their diameter are in this condition. On the contrary, the spherical aberration is sensibly nothing when the diameter of the lens is not greater than the fifteenth of its focal length.

Longitudinal aberration increases or diminishes as the square of the diameter of the aperture, and inversely as its focal length. Lateral aberration is proportional *to the cube* of the aperture, and inversely proportional to the square of the focal length.

Thus, let us compare two lenses of the same material and of

the same radii of curvature, but one of which has double the diameter of the other. The former has a longitudinal aberration four times as great as the latter, and a circle of aberration eight times as great.

Of two lenses with the same aperture, of which the focal lengths are to each other as 1 to 2, that which has 2 as its focal length has half the longitudinal aberration of the other, and only a quarter of the lateral aberration.

The greater the index of refraction of the material of which the lens is formed, the smaller will be, for the same given focal length, its radii of curvature, and consequently its spherical aberration. It follows from this that in objectives which have a given aberration, this could be diminished by employing very refractive transparent bodies.

Figure 31 strikingly exhibits this fact. A and B are two lenses having exactly the same focal length, but formed of different refractive substances. The first is of glass, of which the index is 1·5; the second of diamond, of which the index is 2·5. The radius of curvature of the first is three times as short as that of the second, and therefore it possesses an aberration much more considerable.

Fig. 31.

Minimum of Spherical Aberration.—For a fixed distance of the radiating point situated in the axis of a lens, calculation, agreeing with practice, assigns to it radii of curvature and a position where aberration is the least possible. For this it is necessary to know the index of refraction of the material of which the lens is formed.

Thus with ordinary crown-glass, of which the index of refraction is 1·5, the two radii of curvature ought to be to each other as 1 to 6, the most convex face (of which the radius of curvature is 1) being turned towards the radiating point which we suppose placed at infinity. If the index

increases, the ratio of the two radii of curvature increases also. Thus for the heavy kind of flint (1·6), the plano-convex form is the most advantageous.

For diamond, of which the index of refraction is 2·5, a meniscus would be necessary, of which the convex face should have 2 and the concave face 5 as radii of curvature.

If the radiating point, in place of being situated at infinity, and consequently emitting rays parallel as regards the lens, is near to the latter, it must be treated as emitting divergent rays, and in order that the lens shall present the minimum of aberration its curvatures must be changed. In proportion as the radiating point approaches the lens, the face which is towards it, and which had in the case cited above 1 for its radius of curvature (the other having 6), becomes less convex in relation to the other; for example, 2 to 5, 3 to 4, 4 to 3, 5 to 2 successively, and lastly, if the radiating point reaches the principal focus of the lens, 6 to 1. It is seen, therefore, that the lens is now reversed.

Destruction of Spherical Aberration by the Diaphragm.—Any lens, convergent or divergent, of which the radii of curvature are long or short, and of which consequently the aberration is slight or considerable, is reduced by a small diaphragm placed in its axis, to a plate *a b d c* (fig. 46) which has nearly parallel faces, and thus it is henceforth exempt from spherical aberration. This lens, M, in fact, such as it is represented in our figure, would be reduced to one-sixth of its diameter, while its focal length remains the same; therefore, according to what we have just seen, its lateral aberration would be reduced to a thirty-sixth, that is, would be annulled or nearly annulled. We can convince ourselves of this by presenting the lens to the solar rays falling normally (to the plane of its circumference). With the whole of its aperture the image of the sun is fringed with the lateral aureola due to the aberration of sphericity. The diaphragm being then interposed this aureola disappears, and the image thus becomes incomparably sharper because the

rays refracted by the margin of the lens, which rendered the image indistinct, are cut off by the stop.

Nevertheless the diaphragm never *destroys completely* the spherical aberration of lenses; it only serves to reduce it to a very small quantity. It is, however, completely destroyed in the following way.

Destruction of the Spherical Aberration of a Lens by a second Lens of contrary character.—Let us suppose a lens, L, (a convergent one, for example,) the aberra-

Fig. 32.

tion of which it is wished to destroy completely along its axis. The expression $f f'$ of the aberration is furnished to us by the points where a ray infinitely close to the axis and an extreme ray (both parallel to the axis) cut the axis after emerging from the lens. Now let us associate with the convergent lens L a divergent lens M.

It is easy to conceive that this divergent lens, *if its radii of curvature are suitable*, will scarcely at all change the direction of the ray $b f'$, which will only be deviated to F, f' F being a very small quantity, whilst it will greatly change the direction of the ray $a f$ (since its prismatic form is greater at the margin than at the centre) so as to direct it also to the point F.

Such an association of lenses forms, as a whole, a single lens, convergent, but free from spherical aberration. Such lenses are called *aplanatic*, and calculation indicates with absolute exactitude their numerical data.

The divergent lens M may have a common face with the lens L, and the two lenses be then cemented together. The two lenses may also be separated by a larger or smaller interval, and consequently have a different diameter.

An example of such an aplanatic combination will be found, in the chapter on enlargements, in the dyalitic apparatus. The convergent lens in this system has a diameter of nineteen inches, and a focal length of thirty-eight, and its spherical aberration is corrected by a lens of nine and a half inches, which is hardly one centimètre thick at the margin, and which scarcely lengthens the focal distance of the other.

The nature of the glass may be the same for the two lenses, or, as is most generally the case, it may be different; because, as we shall soon see, the negative lens most frequently not only corrects the spherical aberration, but also the *chromatic aberration*.

As chromatic aberration always surpasses in importance spherical aberration, and, consequently, as it is desirable above all to correct the former, it frequently happens that the negative lens corrects too much or too little the spherical aberration of the convergent lens with which it is associated. If it corrects aberration too much, the system is said to possess spherical aberration of a *negative* character, because then the rays emerging from the margin cut the axis farther away than those from the centre. If it correct too little, the aberration is *positive*.

It is impossible to construct a convergent lens, or to associate two or more of them on a common axis, in such a way as to destroy their spherical aberration. Many treatises on physics contain the contrary assertion,* but this is an evident error.

It is needless to add, in finishing this paragraph, that it is necessary for correcting the aberration of convergent lenses to

* M. Daguin and many other authors of works on physics repeat this error, which originated in a memoir of Sir John Herschel, in which the illustrious astronomer, having fallen into an error in interpreting the figures of his analytical formulæ, gave combinations of convergent lenses which ought to have been aplanatic, and which are not so. Sir John Herschel, however, rectified this error in his memoir several years afterwards.

associate with them divergent lenses, and conversely for correcting the aberration of the latter to associate with them the former.

Spherical Aberration of Pencils oblique to the axis; Coma.—We have hitherto only considered the aberration of pencils parallel to the axis of lenses, but in photographic objectives which include a very considerable angle (from 30° to 90°), what we have said is only applicable to a small portion of the objective, namely its central part. We have therefore also to examine the aberration of pencils very oblique to the principal axis of a lens, both by a single lens and by an aplanatic system of lenses.

When parallel rays of light strike a lens obliquely, the longitudinal aberration alters for two diameters of the lens (perpendicular to each other), and is the greatest in the plane passing through the axis of the lens and the radiating point. It follows from this that the aureola A (fig. 33)—circle of aberration—which surrounds the image of a luminous point at the focus of a simple lens, circular if this point is situated in the axis, lengthens according as the point departs from the axis and takes the forms B, C, D, which lengthen more and more until terminating in a point at their upper part, which has given them the name of *Coma.*

Fig. 33.

An aplanatic system—that is, one perfectly free from spherical aberration along its axis—is no longer free from this aberration if the pencils fall obliquely to its axis.

Let A B (fig. 34) be a simple plano-convex lens, H F an axis passing through its optical centre, and making with its principal axis D E a considerable angle (15° to 30°, for example), and R I, R I * two parallel rays, striking the lens

* In figs. 34 and 35, R I indicate the incident rays, R R the refracted rays, M the normals to the convex face, M' the normals to the plane face A C, C B, the tangent *planes at the* points of incidence or emergence.

above and below H F. The upper ray will cut the axis at

Fig. 34.

Fig. 35.

F′, and the other farther off at F. The image of the luminous point will no longer be a single point, but will appear to be furnished with a tail or *coma*,* which is directed downwards. In consequence, rays coming from the lower part of the lens are more condensed in a point F than those coming from its upper part, which are dispersed beneath this point after having cut the axis in F′.

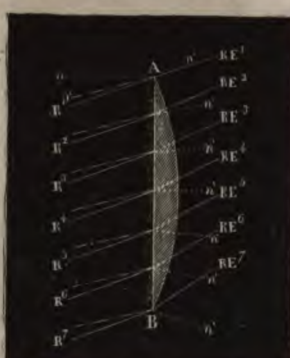


Fig. 36.

If the lens be turned the other way (fig. 35), so that incident rays fall on its convex face, the coma, in place of being directed inwards, is directed outwards.

If, instead of considering only two incident rays, we take an infinite number of rays, R^1, R^2, R^3, &c. (fig. 36), striking obliquely the plane surface of a plano-convex lens A B, there will be, for every two rays immediately adjacent taken in the plane passing through the prin-

* J. Lister. *On some Properties of Achromatic Object-glasses.*—Phil. *Transactions* (1830.)

cipal axis, a different focal distance. The construction of the figure shows that R^1, R^2, &c., being parallel after refraction at the plane surface of the lens along the dotted lines r, will all emerge along RE^1, RE^2, &c., making different angles with the normals n' to the curved surface at the points of emergence, and with the oblique axis R^1 RE^1 which we have (arbitrarily) chosen. So the incident pencils, R^1 and R^2, R^2 and R^3, &c., will have for focal distances (fig. 37) the points f^2, f^3, &c.

Fig. 37.

Destruction of Aberration of Pencils oblique to the axis.—By properly selecting the radii of curvature of the two lenses which form the single combination employed in photography (corrected for chromatic aberration along its principal axis), and by placing in front of it a diaphragm, of which the aperture does not exceed 1-30th of its focal length, its spherical aberration is reduced to a very small amount, both for pencils parallel to the axis and for pencils very oblique.

The diaphragm must be placed at a suitable distance from the lens. This makes of it, therefore, an assemblage of lenses, each of which has sensibly the diameter of the aperture of the diaphragm, and each of which acts specially on pencils more or less oblique, the centre of the lens receiving rays only from points of the object situated along the axis, while all others are shut off, and the margin receiving them only from points of the object situated very obliquely.

We shall, however, explain these things more fully when treating of *the diaphragm* (see p. 89).

Effect of Spherical Aberration in Photographic Objectives, and how it is proved.—The effect of spherical aberration in the systems of objectives employed in photography, is to destroy the sharpness of the image both at its centre and at its margins. We can experimentally prove this by removing the diaphragms of the objective, known among photographers under the name of *single landscape lens*, and by examining the image the objective gives. It is utterly wanting in sharpness.

In other objectives in which spherical aberration is corrected by the arrangement of the lenses which form them,—for example, in the objective known under the name of the "*portrait combination*,"—to discover if this aberration is altogether destroyed, examine the image of two small circles of tinfoil* fastened to a window exposed to direct day-light, so as just to touch each other. Whilst the image is being examined with a magnifier, put a diaphragm on the objective so as to reduce its aperture to a half. If, in this case, the image of the circles of tinfoil gain in sharpness, which will be best observed at their point of contact, the aberration is not completely corrected.

This trial must be made along the axis of the objective, because it is only along the axis that spherical aberration can be completely corrected.

If, after having put on the diaphragm, it becomes necessary to draw back the focal plane (the ground-glass of the camera), to preserve the primitive sharpness of the image, the objective possesses *positive* aberration; if it is necessary to advance it, *negative* aberration.

The examination, however, may be made still better by reproducing the wafers by photography, first with the whole aperture of the objective, then with a small diaphragm on the objective, and without changing the focus. The two images should be equally sharp.

* Two wafers answer equally well.

Spherical Aberration serves to divide Photographic Objectives into two very distinct classes.—There are different forms of photographic objectives. Some can be employed with their entire aperture, and then give a sharp image, but of little extent; the others (employed with their whole aperture) give only confused images. This is because the former are *aplanatic*—that is, because their aberration is corrected by the arrangement of the lenses which form them, and the second are not so. The aplanatic photographic objectives comprehend—

1st. The *double lens* of M. Petzval.
2nd. The *orthoscopic* of M. Petzval.
3rd. The *triplet* of M. J. H. Dallmeyer.

The *non-aplanatic* objectives comprehend—

1st. The ordinary *single lens*.
2nd. The *single objective* (of three lenses) of M. Dallmeyer.
3rd. The *doublet* of Mr. Thomas Ross.
4th. The *globe-lens* of Harrison and Schnitzer.
5th. The *panoramic lens* of Mr. Sutton.
6th. The *doublet* of M. Steinheil.

An attentive examination of the latter class of objectives demonstrates that the sharpness of the images which they furnish (even when they are employed with very small diaphragms) is not so perfect as that of the images produced by aplanatic objectives; especially if we compare, in the first series, the orthoscopic and the triplet (which are the most aplanatic), with the globe-lens, which possesses a very considerable spherical aberration. We may satisfy ourselves on this point by examining the image of very fine black letters pressed on a very smooth white ground—engraved visiting-cards, for instance. Aplanatic objectives cause no loss of the finest details, whilst the others cause them to disappear. It is particularly at the centre of the image (which corresponds to the axis of the objective) that it is necessary to make this comparison. It is necessary besides, in this trial, to furnish the objectives with diaphragms of which the aperture is proportional to *their respective* focal length (1-30th).

Section II.—*Chromatic Aberration.*

Visual and Chemical Focus.—The image of a white point, A (fig. 38), situated at a distance from a lens, L, which is formed at its principal focus, R, is deficient in sharpness, because it is there surrounded by a violet aureola. At V, nearer the lens, the image of the point is surrounded by a red aureola.

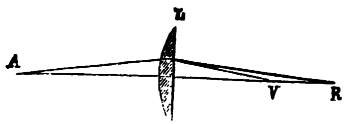


Fig. 38.

This results from the fact that the white point, A, emits rays of different refrangibility. After refraction these rays are separated, and the violet, being more refrangible than the red, have their focus at V, while the red have theirs at R.

If we wish to obtain from the point A a photographic image by using a simple lens, L, we shall find that by placing the photographic surface at R, where the image of the point appears the clearest to us, we shall obtain but a confused image of it, and that, by successively advancing the photographic surface towards the lens, the image obtained will be more and more sharp up to V, where it will be perfectly distinct.

This is because those rays which have the greatest brightness to the eye, and which are found to have their focus precisely at R, where, consequently, the image appears the clearest to us, have scarcely any influence on photographic surfaces; whilst those the most obscure (blue, indigo, violet), which almost escape our eye, are precisely the most active in regard to the photographic surface.

If therefore we used as a photographic objective a simple lens, even though this should be limited (as is shown in figure 38) to a very small aperture, so as to reduce the spherical aberration to a small quantity, the exact focussing of the image on the ground-glass, for the eye, would not be so for photographic surfaces, which give in place of a sharp image a confused one.

Hence the names of *visual focus*, to indicate the focus of a lens as judged of by the eye, and of *chemical focus*, to indicate its focus as determined by photographic surfaces. These two foci in a photographic objective ought to coincide, else the objective is said to have a chemical focus.

If the reader recall to mind what we have said at page 29 about dispersion by prisms, and at page 51 about the focal length of lenses, he will very easily determine for himself the value of the difference between the visual and chemical foci, when the focal length of the lens and its index of refraction, or, what comes to the same thing, its radii of curvature, are known. Thus, suppose it is wished to know what will be the chemical focus of a plano-convex lens of which the radius of curvature is 1 mètre, the index of refraction of the yellow being 1·5, and that of the violet 1·52. The formula $f = \frac{R}{n-1}$ gives us for the focus of the yellow 666 millimètres, and for the violet 658 millimètres. The chemical focus thus differs from the visual by 8 millimètres.

In reality this focus would be much more considerable, because, instead of considering only the central part of the lens, which is free from spherical aberration, account must be taken of the error arising from the margin of the lens, the spherical aberration of which is considerable. The chemical focus would therefore be reckoned from the absolute focus (that of the yellow rays emerging from the central part of the lens), to the focus of the blue rays emerging from the peripherical part of the lens—blue rays which cut the axis so much the nearer the lens as its aperture is larger, a fact arising from spherical aberration. Hence the necessity, in achromatising a lens, of first destroying its spherical aberration.

Destruction of Chromatic Aberration.—The most simple way to achromatise a lens (or a system of lenses) consists in placing in front of it a vessel with parallel glass sides, containing a solution of chloride of copper in ammonia. This liquid is of a deep blue. It is, however, diluted with water

so long as the solution, though being less deeply tinted, allows only blue colour to pass through. This is easily ascertained, by looking through a prism at a strip of white paper placed in front of the vessel. Seen directly, the strip is fringed with red and yellow at one side, and blue and violet at the other. Seen through the blue solution, the red and the yellow disappear completely if the solution be of the proper tint.

The ammoniacal chloride of copper, therefore, by allowing only the blue to pass through, achromatises simple lenses, and also allows the passage of the chemical rays; still it absorbs a great part of these, and its use would, besides, be very inconvenient.

Since the diaphragm applied in front of a lens does not correct chromatic as well as spherical aberration, it is, therefore, absolutely necessary to proceed with lenses, as with prisms, by associating with them a second lens of different dispersive power. After what we have seen at p. 31 *et seq.*, the explanation of the achromatising of lenses will present no more difficulty.

Fig. 39 shows how these lenses are combined. The first, of the upper row is a divergent meniscus; the second, a plano-concave lens; the third, a bi-concave lens with faces equally concave. The lenses beneath are similar, but convergent. Ordinarily, in an achromatic combination, the convergent lens is of *crown-glass*, the divergent of *flint-glass*, and the two have one face common, at which they are cemented together.

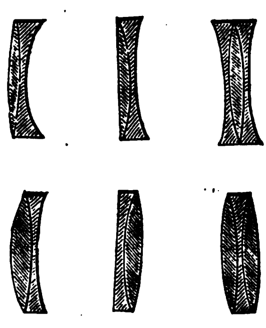


Fig. 39.

Suppose the case of the achromatism of a bi-convex lens of crown-glass, of which R and R′ are the radii of curvature, and n_v and n_r the indices of refrac-

r the red and the violet. The focal lengths, f and f_1, lens will be—

$$f = \frac{R\,R'}{(n_r - 1)\,(R + R')}$$

$$f_1 = \frac{R\,R'}{(n_v - 1)\,(R + R')}.$$

sociate with this convergent lens a divergent one, having ace common with it, R′, and the other unknown, R″. But ll necessarily be negative, since it belongs to the diver- lens. Let n'_r and n'_v be the indices of refraction, and we have for their focal lengths—

$$f' = \frac{R'\,R''}{(n'_r - 1)\,(R' - R'')}$$

$$f_1' = \frac{R'\,R''}{(n'_v - 1)\,(R' - R'')}.$$

ow, let the reader recall to mind the formula which con- the distance, p, of the radiating point, and that, p', of the igate focus, with that of the principal focus :—

$$(1) \;\ldots\; \frac{1}{p} + \frac{1}{p'} = \frac{1}{f},$$

let him take into account that the negative lens lengthens focal distance p', which becomes p'', by giving a new cipal focal length f' for the combination. From this ave—

$$(2) \;\ldots\; \frac{1}{p''} - \frac{1}{p'} = \frac{1}{f'}.$$

hese two equations added together give—

$$\frac{1}{p} + \frac{1}{p''} = \frac{1}{f} + \frac{1}{f'} \text{ and } \frac{1}{p} + \frac{1}{p''_1} = \frac{1}{f_1} + \frac{1}{f'_1}$$

f_1, f_1', referring to the violet, and p'', f and f' to the red.

Now, in order that achromatism may result from the association of the two lenses, p'' and p_1'' must be equal—that is, the focus of the red and that of the violet must form at the same point. These values will be equal if the resulting system allows us to write—

$$(3) \ldots \ldots \frac{1}{f} + \frac{1}{f'} = \frac{1}{f_1} + \frac{1}{f'_1}.$$

In these equations, let us substitute the values of f, f', f_1, f_1', obtained above as functions of R, R′, R″, and n, n', and we shall derive from them—

$$R'' = \frac{R R' \, (n'_v - n'_r)}{R\,(n'_v - n'_r) = (R + R')\,(n_v - n_r)},$$

$$R'' = \frac{R\,(n'_v - n'_r)}{(n'_v - n'_r) - 2\,(n_v - n_r)}.$$

Now, R and R′ are known, being the radii of curvature of the convergent lens; the indices of refraction of crown and flint-glass are also known; and therefore the divergent lens of flint-glass will have for its radii of curvature R′ and R″.

We here suppose the aperture of the lens to be very small, for we do not take into consideration the thickness of the lens.

Moreover, we have not here considered the spherical aberration either of the first or second lens, and this ought to have been done.

Destruction of Chromatic and Spherical Aberrations in Lenses of large aperture.—It is easy to connect together the equations which enable us to construct aplanatic lenses, and those which enable us to achromatise them; but these equations, otherwise very simple, only apply to the case where the lens has a very small aperture, that is, where its thickness can be regarded as nothing.*

* Equations can be laid down in which a second approximation takes thickness into account. By employing them, the calculation is much abridged.—(See Coddington: *Treatise on Optics.*)

Now, if the lens possesses a considerable diameter relatively to its focal length, these formulæ, at the most, can only apply to the central part of the aplanatic and achromatic system; and they therefore serve only to give the numerical elements of this part. But it is essentially necessary that the rest of the surface of the lens should present the properties of its central part; and it is the accomplishment of this which constitutes the real difficulty for the optician.

In fact, in an achromatised aplanatic lens, it is not only necessary that the rays falling on its margin and on its centre (parallel to its axis), should emerge from the lens so as to cut the axis at the same point, but it is also necessary that the rays falling on the intermediate parts of the lens should present the same property. The negative lens of an achromatic system ought therefore, in the first place, to correct the spherical aberration of the positive lens with which it is associated (without this, perfect achromatism is impossible), and, next, to correct the aberration of refrangibility. It may fulfil the first condition without fulfilling the second; but it cannot fulfil the second without also satisfying the first, at least from a theoretical point of view.

The formulæ which are applicable to an achromatised aplanatic lens of large aperture cannot be converted into numerical data, on account of the much greater number of unknown quantities which they contain when a greater approximation is sought. It is necessary, therefore, to have recourse to experiment by re-working the surfaces several times, and this operation is sometimes very long and laborious.

Chromatic aberration of pencils oblique to the axis.—Since it is impossible to construct a lens free from spherical aberration both along its axis and oblique to it, so lenses cannot be constructed free from chromatic aberration under these same circumstances. For a combination of lenses may be assimilated to a combination of prisms, and we have seen that achromatism of a prism is only possible in relation to rays of a *fixed incidence* (page 32, line 16).

Let M (fig. 40) be a bi-convex lens of crown-glass, achromatised for incident rays parallel to its axis, C C′, by the plano-concave lens of flint-glass, N, and let R O be an incident ray oblique to the axis. This ray, on emergence, will be decomposed in the direction $r\,o'\,v$, which forms the angle of dispersion. The part of the lens traversed by the ray may be represented by the prism (of dotted lines in the figure) $o\,a\,o'$; $a\,o$, $a\,o'$, being the normals drawn to the points of immersion and emersion. Now, the angle, i, which the incident ray, R O, makes with the parallel, $o\,a$, to the bisector, $a\,m$, of the prism, a, is much greater than the angle, i', made by the emergent rays with the parallel, $o'\,a'$, to the same bisector, $m\,a$. Now, that the angle of dispersion, $r\,o'\,v$, may be as small as possible, these angles, i and i', should be equal, which would assign the position $x\,y$ to the bisector, $a\,m$. Therefore the lens, reversed would fulfil this condition better, and it is in fact in this way that it is employed in the *single objective;* but, to fulfil it completely, a meniscus, of which the concave surface facing the radiating point has a short radius of curvature, is more favourable. *M. Dallmeyer* is the first optician who has constructed the single combination in accordance with this theory.

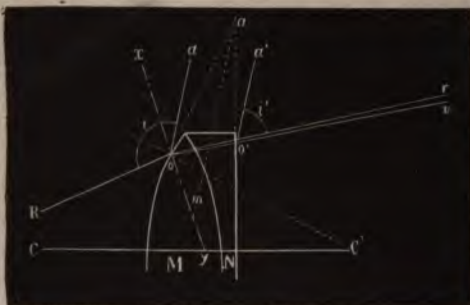


Fig. 40.

The objective which we represent in fig. 41 under the form of a simple lens, although in reality there should be three of them cemented together, is a convergent meniscus, M, of which the face P turned towards the objects for reproduction is concave, and of a radius of curvature relatively very short.

Along its principal axis, C C, this objective is quite free from chromatic aberration; but for very oblique pencils, such as R O, achromatism no longer exists. In front of the objective is a diaphragm, D, which limits the extent of the incident pencils. Let R O be an incident ray very oblique to the axis, N O the bisector of the prism represented by the two faces tangent at the points of immersion and emersion of the lens traversed by this ray; and we shall find that the refracted rays R O and R V form with this bisector, the angles N O R, N O V′, sensibly equal to each other and to the angle N O R′. The angle of dispersion, R′ O V′, which is the direct measure of the chromatic aberration, is therefore very small, whereas it is very considerable in ordinary single objectives.

Fig. 41.

The impossibility which exists of correcting at once, in the same lens, chromatic aberration both along the axis and obliquely to it, has a very troublesome consequence. This is why (using the language of photographers) if a sharp image on the ground-glass is likewise so on the photographic surface, thus proving that the objective is without chemical focus, such is only the case at the centre of the ground-glass. If this experiment be made at the edges of the ground-glass, an image, perfectly sharp to the eye, is not so for the photographic surface; because there exists, for pencils oblique to the axis, a chemical focus, often considerable, which it is very important to reduce to the minimum.

Position of the Chemical Focus as regards the Visual Focus.—It may happen that, the dispersive powers of the materials forming the objective not having been exactly measured, the chromatic aberration may be under or

over corrected. In the former case, the violet having its focus nearer the lens than the red, the chemical focus will be situated nearer the lens than the visual focus. If, on the contrary, the chromatic aberration is over-corrected, the red will then have its focus nearer the lens than the violet, and the chemical focus will be situated further away from the lens than the visual focus. From this it will be seen, therefore, that it is exactly the same with chromatic aberration as it is with spherical aberration; a convergent combination of two lenses, the one convergent, the other divergent (the combination being convergent), may offer the characters of negative aberration proper to negative simple lenses.—(See p. 69).

SECTION III.—*Aberration of form of the image, or curvature of the field.*

The curved Image.—The image of external objects formed at the focus of a lens cannot be received on a plane screen, as we have hitherto supposed it to be (see p. 56): the screen ought to have a concave form, which constitutes the *curvature of the field* of the image. Thus, let us select in a plane very distant, three points, A B C (fig. 42), very nearly

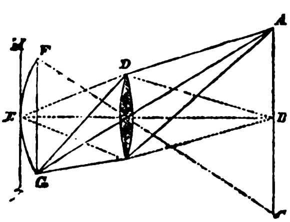


Fig. 42.

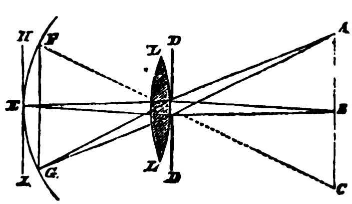


Fig. 43.

equally distant from the convergent lens, D, one of the points, B, being in the axis of this lens, and the two others without it; and let us examine the form of the image behind this lens. It is evident that the image of the three points will *be formed* at distances from the optical centre of the lens, D,

nearly equal to its principal focal length. The field, F E G, will therefore be curved, and the image cannot be received on a plane, H I, without sacrificing the sharpness of the image of the points A and C.

This aberration of lenses is generally attributed by photographers to spherical aberration. They imagine, on seeing the image sharp at the centre of the ground-glass of the camera and confused at its edges, that this effect is due to the sphericity of the faces of lenses. But this has nothing to do with it, for a lens with parabolic curvatures would give the same result.

Before explaining how the aberration of form is corrected, we must see what is meant by the *depth of focus* of a lens, and by the *diaphragm*.

Depth of Focus.—Depth of focus is the property of lenses of giving a clear image in planes of which the distance is unequal. It follows from this that the ground-glass placed at the focus of a lens may be moved to a very slight extent without the image sensibly losing its sharpness.

To prove this experimentally, bring a camera furnished with a single combination to bear on a landscape. Bring to a focus the objects farthest off. We shall soon remark two things: the first is that the ground-glass can be advanced or withdrawn to a small extent without the sharpness of the image of a fixed plane of the landscape sensibly changing; the second is, that if we bring to a focus the most distant plane, many other nearer planes will still be in focus.

The same experiment can be made with an opera-glass, which may be regulated for distant objects so as that they may be seen very distinctly. If you now direct the glass to nearer objects you will also see them with perfect clearness. Similarly, by holding the opera-glass directed on a distant object, you will see that you can move the eye-piece a short distance without lessening sensibly the sharpness of the image by doing so.

It is to be observed that the depth of the focus varies with

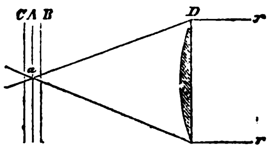


Fig. 44.

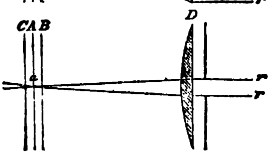


Fig. 45.

the aperture of the lens. Figures 44 and 45 make this very plain. In figure 44 we make use of a lens with its entire aperture. The rays, *r r*, emanating from a distant point, form, after having traversed the lens D, the image of the point at *a* on a screen or ground-glass A. But if the ground-glass be either drawn back or advanced, to C or to B for example, the image of the point immediately spreads out in a circle, because angle *a* is very large. When the same lens D (fig. 45), is reduced to its central part by a stop, the image of the point is still formed at *a*, but the ground-glass can be placed at C or at B, without the image of the point becoming now appreciably altered. This is because in fig. 44 the rays, *r r*, emerging from the lens, are much more convergent than in fig. 45.

It results, therefore, from the preceding, that a convergent lens is capable of giving a sharp image of planes distant from each other, contrary, apparently, to the law of conjugate foci. But experiment shows that it is only on the condition that these planes are sufficiently distant from the lens that their image may be formed near the principal focus. Thus, the nearer objects approach the lens, the less becomes this depth of focus, as is shown by the following short table, which gives the focal lengths of a lens of 10 cent. focus, for objects of which the distance is constantly diminishing.

Distance of object.	Elongation of focal length of the lens.
10,000 mètres.	0·001 millimètres.
1,000 ,,	0·01 ,,
100 ,,	0·1 ,,
50 ,,	0·2 ,,
10 ,,	1·01 ,,
5 ,,	2·04 ,,

Distance of object.	Elongation of focal length of the lens.
4 mètres.	2·6 millimètres.
3 ,,	3·5 ,,
2 ,,	5·3 ,,
1 ,,	11·1 ,,
50 centimètres.	25 ,,
40 ,,	33·3 ,,
30 ,,	50 ,,
20 ,,	100 ,,

This table is very instructive. It enables us to see clearly that for objects 50 mètres distant, for example, the focal length of the lens is increased only two-tenths of a millimètre, a length quite inappreciable; for 10,000 mètres it is increased still less, only a thousandth of a millimètre. Therefore, all objects situated more than 50 mètres from the lens will be in focus on the ground-glass, however great may be their distance.

When, on the contrary, the object is situated very near the lens—for example, 30 centimètres from it—the ground-glass has to be drawn out 5 centimètres; when at 50 centimètres, the glass has to be drawn out 2½ centimètres; when the object is distant one mètre, the glass has to be drawn out 11 millimètres,—quantities relatively great. For this reason, objects situated at a short distance from the lens give sharp images only on the condition that they are very near each other; hence the difficulty of obtaining the image equally sharp if this condition is not fulfilled.

Thus, then, the depth of focus of the lens varies with its aperture, and the distance of the objects which form the image at its focus. It varies also according to the form of the lens or the optical combination of lenses composing an objective. Convergent meniscus lenses have the greatest depth of focus when their concave face is towards the objects. Among objectives composed of several lenses, the *orthoscopic* has the greatest depth of focus, and the ordinary *double combination* the least. This is because the former has generally a *small aperture* in relation to its focal length,

and because, moreover, the divergent lens placed along with the anterior convergent lens renders the emergent pencils less convergent. The second, on the contrary, has generally a very large aperture, and besides, the rays emergent from the first lens (the one which is towards the object) are rendered still more convergent by the second lens.

Effect of depth of Focus on the curvature of the field.—Figure 42 shows that if a ground-glass, H I, is placed at the principal focus of the lens, D, there is but one point sharply defined in the image of the points A, B, C, which is E; if the ground-glass is brought nearer to the lens, the point E will then become indistinct, and the points F and G will gain in sharpness, but it will be impossible, with the entire aperture of the lens, to render the image of the three points equally sharp at the same time. But let us see the effect of a stop, D D, placed close in front of the lens (fig. 43), and let us compare the two figures 42 and 43 with the figures 44 and 45, it will be seen at a glance that the ground-glass, H I (fig. 43), on which the point E was alone in focus in the preceding example, can be brought a little nearer to the lens without the image sensibly diminishing in sharpness in consequence. Similarly, another ground-glass which would pass through the points F and G could be brought a little farther to the lens without the points F and G losing their sharpness on this account. There is, therefore, between F G and H I such a position for the ground-glass that the three points, F, E and G, will all three be approximately sharp.

The office of the stop which reduces the aperture of a lens to its central part is of great importance. In reality it serves only to increase the depth of focus of the lens, and it is owing to this property that a lens can give a sharp image on a plane surface. The experiment is easily verified by directing on any plane whatever—a geographical map for example—a camera furnished with a *reversed* single combination, all the diaphragms of which have been taken away. We can only succeed in rendering the centre of the image

sharp, or a small square situated symmetrically around the centre. Now put on a very small diaphragm, and you will observe that sharpness will be distributed over a surface of the ground-glass much more extended.

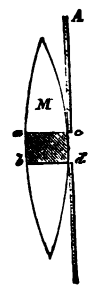


Fig. 46.

The Diaphragm.*—If the stop, A, be placed as we have shown in fig. 43, that is, close to the lens, M, it is the same as if the lens were very small relatively to its focal length. In this case observe that, if it be very small, the lens may be considered as a plate with parallel faces *a b*, *c d* (fig. 46), that is, therefore, nearly as if there were no lens there. The field of the lens will certainly not be so curved as if the lens were employed with its entire aperture, but it will still be much so, because of the *depth of focus*; that is, the extent to which the ground-glass can be safely moved without putting the image out of focus is as a whole very slight, and because the curvature of the field is very great. Let us see what takes place when the stop is removed from the lens to a proper distance. In this case the stop becomes a diaphragm.

Let A, B, C be three very distant radiating points (fig. 47), L L a convergent lens. Let us trace, behind the lens, the course of the rays emitted from the three points, A, B and C. The rays coming from the point B (which we suppose to be situated at infinity and on the axis) reach the lens parallel to each other and perpendicular to its surface, from which they will proceed to form the image of the point B at F, the principal focus of the lens, L L. But it is not

* In optics, *stop* and *diaphragm* are synonyms. But in photographic optics they are only so by an unfortunate confusion of language. The stop reduces the lens to its central aperture; the diaphragm, on the contrary, allows all the segments of the lens to act, but only on the different radiating points placed symmetrically and concentrically in relation to the axis of the lens, or of the system of lenses (of which the axis is, besides, in every *case common*).

thus with the rays which emanate from the points A and C situated without the axis of the lens. The ray A^1 will be

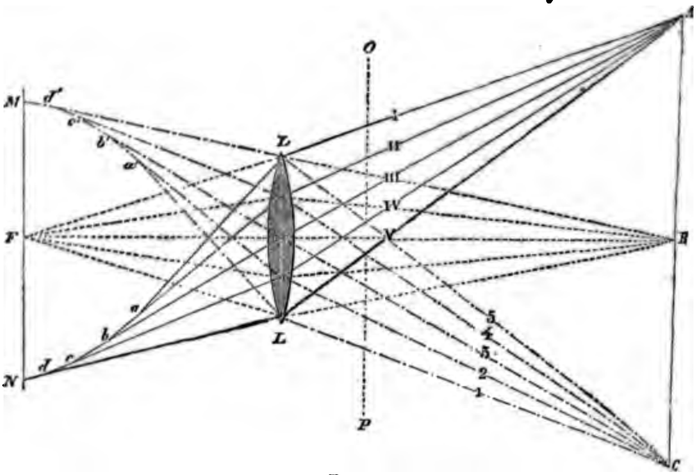


Fig. 47.

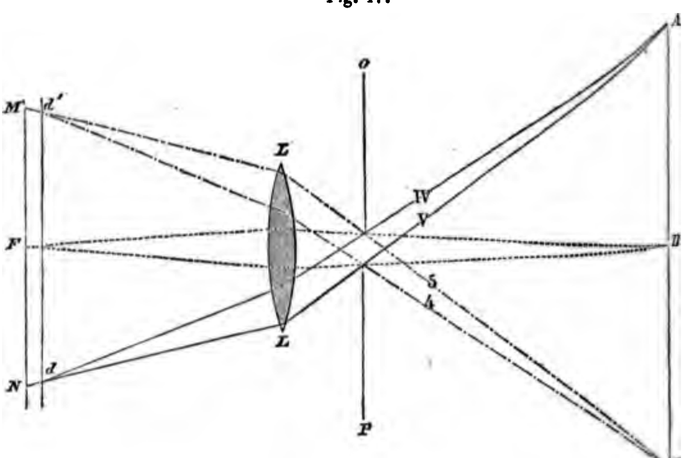


Fig. 48.

refracted to a; A^2 to b; A^3 to c; A^4 to d; A^5 to N. It is *the same* with the rays 1, 2, 3, 4, and 5 emitted by the point

C. (This effect is due to spherical aberration, of which we have spoken, p. 72.) For this reason, the ground-glass placed at the principal focus, F, will not receive a sharp image, but an indistinct one. The experiment can easily be made by examining the image of a landscape at the focus of a photographic single objective. Even should the ground-glass have the form of a spherical cup, the image would still be indistinct, because all the rays emanating from points out of the axis of the lens arrive at different points behind the lens. To have a sharp image, a diaphragm must therefore be placed in front of the lens; but where it must be placed and what its aperture is to be, is the question.

Observe in the figure that the only pencils coming from the points A and C, which arrive and form their focus very near to the focal plane M N, are the pencils A^4 and A^5, and C^4 and C^5. Let us place the diaphragm at O P, so as to allow only these pencils to pass, then our figure becomes exactly the other (fig. 46); but we already know that lenses with a diaphragm have a certain depth of focus, and that consequently the ground-glass can be slightly moved without the sharpness of the image sensibly changing. Now, if the distance M d^1 or N d is not greater than the depth of focus, then the dimension and position of the diaphragm will be determined. It is easy to see, that the smaller the diaphragm, the more must the image gain in sharpness; since the rays which confuse the outlines of the image are arrested by the diaphragm.

The diameter of the diaphragm necessarily depends on the expression of the spherical aberration for rays oblique to the axis of the lens L L. The smaller the aberration, the greater may be the diaphragm; the greater the aberration, the smaller must be the diaphragm. There is, however, a limit to the smallness of the diaphragm, because of *diffraction* (see p. 5), which would have the effect of causing in the image a confused outline of very bright objects. The image of a star, instead of being a single point, would be a point surrounded by *concentric rings*. If the diaphragm which is

placed in front of lenses be smaller than 1-60th of their focal length, the image tends to become less sharp in consequence of diffraction.

Let us add that, photographically speaking, diaphragms, too small, give flat images, without either relief or effect. It should never be necessary to employ diaphragms of which the aperture was less than one-thirtieth of their focal length; and it is chiefly for this standard that we prefer the use of aplanatic objectives (see p. 75).

Destruction of Aberration of Form.—Now that we understand the use of the diaphragm, which divides the lens into as many parts as there are incident pencils more or less oblique, we can examine more precisely the cause of curvature of the field, and how this field may be rendered flat.

In the first place, experiment has shown that, among simple convergent' lenses, convergent meniscuses furnished with a diaphragm properly placed are those of which the field is the least curved, on the condition, however, that their concave face is presented towards the object to be reproduced. The field is even completely flat if the lens does not include a considerable angle (10° or 15°, for example). But, for the purposes of photography, this lens should include an angle at least double of this. Now, in this case the field becomes much curved, and the image completely loses its sharpness towards its edges.

Thus, let M L be a convergent meniscus furnished with a diaphragm N O, R a luminous pencil emanating from a point situated at infinity in the axis of the lens, and R′ an oblique pencil falling on the margin of the lens. The focal plane P F will be deter-

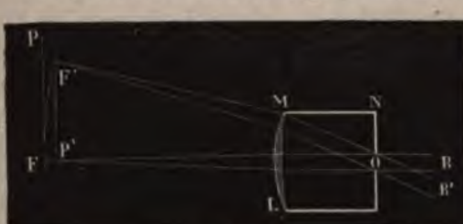


Fig. 49.

nined by the focal length of the lens (where the rays R have their focus). The focal length of the oblique pencil R′ will not be equal to the other, *but much shorter*, M F′; so that the focal plane F P will be curved, F P′ × P′ F′ being the measure of the curvature of the field. Suppose we use a negative lens instead of a positive one, and exactly under the same conditions. It is understood that we should not have a real image, but only a virtual one. In this case the curvature of the field would be reversed, since the margins of the lens have a *greater* focal length than the centre, a result precisely the converse of that obtained with the convergent lens.

But simple or uncorrected lenses cannot be employed in photography, because of the chromatic aberration, the result of which would be a considerable distance between the visual and chemical foci. Hence the necessity of employing achromatic lenses which, as is known, are composed of a positive lens associated with a negative lens. Now, by properly combining these two lenses, the aberration of form in which is opposed, as we have just seen, we succeed in rendering the field completely flat, that is to say, in rendering their focal length for pencils oblique to the axis equal to that for pencils parallel to this axis.

There exists, therefore, between the position of the diaphragm and the negative and positive radii of curvature of the lenses which form an objective, a relation such that the field can be rendered flat at the same time that achromatism is obtained. If the relation between the radii of curvature of the three surfaces forming an achromatic lens be not exact, the field may be curved either like that of a simple convergent lens, or like that of a simple divergent lens. Thus the achromatic plano-convex lens L M (fig. 50), formed of a plano-concave of flint-glass, and a bi-convex of crown-glass, has for oblique incident pencils, R′, a focus, F′, nearer the lens than for central pencils, R, of which the focus, F, is farther off. Therefore this lens, although achromatic, possesses the curved field analogous to that of simple convergent lenses.

An achromatic convergent lens, L M (fig. 51), of which the flint-glass is biconcave and the crown-glass biconvex, may have properties the converse of those in the preceding case, and have a curved field analogous to that of simple divergent lenses, although convergent.

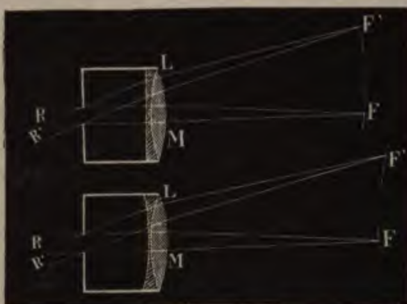


Fig. 50.

Fig. 51.

It is therefore necessary, in the destruction of the aberration of form, to avoid going beyond a certain focal length for oblique pencils, or else we fall into the same aberration (of contrary sign).

It is therefore with this aberration as with spherical and chromatic aberrations, in which we can go beyond the corrections, and render the aberrations negative in convergent combinations and positive in divergent combinations.

The single combination employed in photography, as we shall see in the following chapter, possesses a field tolerably flat, whilst including a certain angle. This objective is necessarily achromatic, like all the objectives employed in photography. It is a convergent meniscus, of which the concave face is turned toward the object to be reproduced, and the convex face toward the ground-glass of the camera in which it is mounted. If this lens were employed in the position in which it offers the least spherical aberration—that is to say, the convex face turned towards the object to be reproduced, like the object-glasses of telescopes—then the field of the image would be very curved. Nevertheless, the part of the field bordering on the axis would have a perfect sharpness, even with the entire aperture of the lens; this is conceivable, seeing that for incident rays parallel to its

principal axis, the lens is nearly free from spherical and chromatic aberrations. By associating with such a lens a negative achromatised lens with appropriate radii of curvature, and situated at a certain distance from the first, *M. Petzval* has succeeded in rendering the field of the entire system very flat. His objective bears the name of the *orthoscopic lens.* Fig. 52 explains the principle on which its construc-

Fig. 52.

tion is based. A is the aplanatic and achromatic convergent lens, the convex face of which is turned towards the object to be reproduced; B is the equally aplanatic and achromatic negative lens. The lens A, employed alone, would give a very curved image on the ground-glass, since the focal distance A f' of the oblique pencils, R′, would be much shorter than that, f, of the axial pencils, R. The negative lens, B, lengthens greatly (from f' to F′) the focal distance of the former, since it acts on these pencils by its margins, which are strongly prismatic, while it hardly lengthens the focal distance (from f to F) of the latter. The primitive field, $f\,f'$, is therefore made flat along F F′.

The triplet of M. Dallmeyer is composed of two achromatic convergent lenses situated at the end of a tube. Such a system would have a field extremely curved, but a negative lens placed between the two serves to render the field very nearly flat, as in the case of the orthoscopic lens.

SECTION IV.—*Aberration of thickness of lenses, or distortion.*

Distortion.—Stretch horizontally and vertically some threads across a frame, and examine them through a large and strong magnifying glass, B, mounted in a frame with a handle, A (fig. 53). You will observe, on placing the eye at a distance of two or three feet from it, and on a level with the centre of the glass, that the threads which cross in the line of the two perpendicular diameters of the glass are the only ones which remain straight, the others appearing curved. *Observe in the figure that the upper threads are bent in the reverse direction to that of the lower threads.* This is because the upper part of the lens is a prism with curved faces, of which the edge is precisely in the reverse position to that of the prism with curved faces which forms the lower part. Accordingly, on elevating the lens (whilst the eye is kept in the same position), so that the upper thread may be seen through the lower part of the lens, the thread is immediately curved in the opposite direction. This is what constitutes *distortion.*

Fig. 53.

If the two threads in the middle remain straight, it is because the eye is placed just at the level of the centre, and if the eye be displaced these same threads immediately become curved.

Distortion by divergent lenses is just the reverse of that by convergent lenses. Thus the threads in fig. 53, instead of being bent with their convexity towards the interior, are bent with their convexity to the exterior, like the curved side of a barrel.

The shorter the focus which the lenses employed in this

experiment have, their diameter remaining the same, the greater is the aberration of thickness: this explains itself.

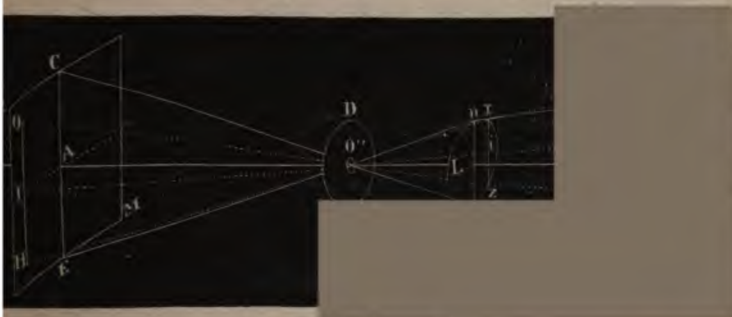


Fig. 54.

Figure 54 makes the effect of aberration of thickness, or distortion, perfectly intelligible. Let L be a convergent lens, in front of which is placed a diaphragm D, pierced at its centre by an opening O″ infinitely small. Let A B be the principal axis of the lens L, K M a plane (situated at infinity) perpendicular to this axis, and K′ M′ the focal plane.

I say that every straight line, C E, passing through the extremity A of the axis B A contained in the plane K M, will be reproduced as a straight line, *n*′ O′. In fact, let us recall to mind that the centres of curvature of the faces of the lens are necessarily in its principal axis; and further, that every refracted ray is always in the plane of the incident ray. Now, the plane of the incident rays C *o*, E *n*, which divides the lens into two equal parts, and which *is perpendicular to the plane of its circumference*, is also the plane of the refracted rays *n n*′ and *o* O′, the intersection of which with the focal plane K′ M′ is the right line *n*′ O′. It would be thus, also, with every other straight line—I A, for example—taken in the plane K M, provided that it passes through the extremity A of the axis.

But it is no longer the same for a straight line, O H, taken in the plane K M, which does not pass through the extremity A of the axis of the lens. In fact, a plane drawn through

this line and the aperture of the diaphragm will be oblique to the axis, A B, and will cut the lens, at x Z, no longer into two equal, but into two unequal parts.

Observe that the rays x H and Z O coming from the extremities of the line O H pass through the lens close to its margins, x and Z, whilst the rays drawn from the aperture of the diaphragm to all the points intermediate between O and H—I i, for example—taken at the middle, pass through farther away from the margin, and where the lens is thicker. The refracted rays, also, which in the preceding case emerge from the lens in a plane perpendicular to that of its circumference, now emerge in a plane oblique to this and along a curved surface which cuts the focal plane in x' i' Z′, having its concavity turned towards the principal axis of the lens. If this lens, L, were formed of an infinity of concentric rings having sensibly the same thickness, the refraction through any point in the surface would be, for a like incidence, equal to that produced by a lens infinitely thin. But formed as it is at present of parts of unequal thickness, the refraction for the same incidence is unequal, according as the ray is incident farther or nearer from the margin; hence the *distortion.*

It is very evident that the distance of the diaphragm from the lens causes the distortion to vary, since the nearer this diaphragm is brought to the lens the closer to the centre of the lens do incident rays of a given obliquity to the axis pass. If the diaphragm be in contact with the lens, the latter, reduced to its optical centre, is evidently free from distortion.

The *single objective* employed in photography does not give images free from distortion; thus a drawing like that represented in fig. 55 is reproduced as in fig. 56. In fact (fig. 58), in the single objective employed in photography,

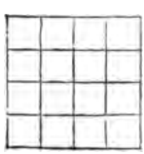


Fig. 55.

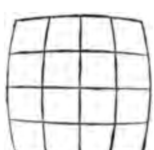


Fig. 56.

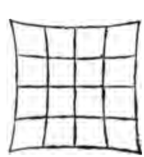


Fig. 57.

e diaphragm when placed at A in front of the lens B has the effect of causing each segment of the lens to act on a different part of the object to be reproduced, C D. Hence distortion in the direction indicated by fig. 56. By placing the diaphragm behind, that is, between the lens and the ground-glass (fig. 59), the distortion would be of the opposite

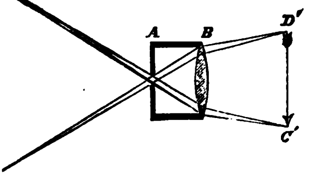


Fig. 58.

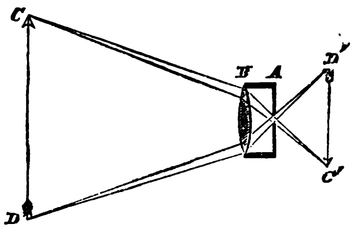


Fig. 59.

kind (fig. 57), since in the former case the ray coming from D traverses the upper part of the lens, and in the latter case the lower part.

Destruction of aberration of thickness.—By uniting two single objectives equal to each other, L L' (fig. 60),

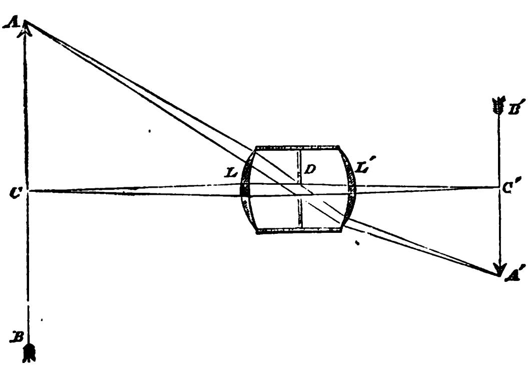


Fig. 60.

and by placing the diaphragm D in the middle, it is easy to see that the rays coming from the point A of an external

object pass through the two opposite parts of the lenses. The first lens gives barrel-shaped distortion (fig. 56), and the second pincushion distortion (fig. 57), but they neutralize each other by being combined.

Messrs. Harrison and Schnitzer of New York (in 1862), and M. Steinheil of Munich (in 1865), adopted this optical system in the "*globe-lens*" and the "*periscopic lens.*" The two lenses (fig. 60) (identical with each other) have the form of meniscuses with their concavities towards each other. The diaphragm is very small, in order to correct the spherical aberration of the combination, which is considerable.

The field is flat, owing to the very peculiar form of the lenses, and principally to the very small diaphragms with which these objectives are supplied.

An English *savant*, Mr. Sutton, in 1858, recommended placing between the two lenses (identical with each other), and at an equal distance from each of them, a concave lens. In fact, by joining two ordinary lenses, A and B (fig. 61)

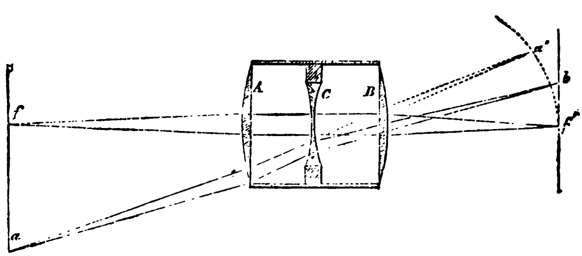


Fig. 61.

(such as the single objectives employed in photography) the field f' a' is very curved. But by placing between the two a negative lens C, the rays coming from a point a without the axis, in place of having their focus at the point a', have it at the point b through the effect of the negative lens. This negative lens increases, therefore, the focal length of the oblique rays. In this case the field is flat, and there is no longer any distortion if the negative lens is bi-concave with

faces identical to each other. This objective has received the name of symmetrical triplet. Such, however, is not the triplet of M. Dallmeyer, who was the first who produced this optical system; Mr. Sutton having only *indicated* the possibility of thus correcting the distortion.*

M. Dallmeyer gives to the two convergent lenses different focal lengths, and places the negative lens between them, the diaphragm being in such a position that the distortion is destroyed, or very nearly so. His system has over that of Harrison and Schnitzer the advantage of a complete absence of spherical aberration; but the negative lens by its thickness still gives a slight distortion, because it is extremely difficult to give it the exact position assigned by calculation, and which varies with the nature of the glass employed. This distortion, however, is only appreciable where the objective is used for a dimension of picture greater than that for which it has been constructed.

* The author's history of the triplet is scarcely so correct as English readers would desire. The following extract, from the seventh edition of *Hardwich's Photographic Chemistry*, supplies the omission :—

"The exact origin of the triplet lens for photographic work is not easy to define, since there are conflicting claims for the honour of first having introduced it. It would appear that, so early as the year 1853, the late Mr. F. Scott Archer was in the habit of using a double combination portrait lens for taking landscapes and interiors, and when thus applied, a stop with a small aperture was placed between the components of the combination, not in the convenient manner subsequently introduced by Mr. Waterhouse, but similarly situated. Mr. Archer, finding that for interiors his lens was sometimes of inconveniently long focus, introduced a slightly convex lens of small diameter instead of the diaphragm, thus shortening the focus and enabling him to include more of the subject on the same-sized plate. Finding this arrangement work satisfactorily, he then substituted, for ordinary landscape purposes, a concave lens of similar dimensions, in the place of the convex, thereby lengthening the combined focus, so as to enable him to use larger plates with the same lens. From evidence still existing, these additions were not empirical, but made with the definite objects in view. The small convex and concave lenses were not at first actinic, from motives of economy—the requisite slight corrections for variation of chemical *focus being* made after focussing. Shortly after Mr.

The double objective of Petzval, when the diaphragms are suitably placed between the two lenses, is very nearly free from distortion. But if the diaphragms are placed in front of the objective, then the distortion is considerably greater than in the single objective.

SECTION V.—*Astigmation, or aberration of position of lenses.*

Experimental process to demonstrate Astigmation. —*Astigmation* is observed with a small portrait combination placed on a large camera, the ground-glass of which is two or three times as great as the surface which this lens ordinarily covers; thus, for example, a quarter-plate lens on a whole-plate camera. Attach to a white wall a black wafer (or one of any other colour), and examine its image at the centre of your ground-glass, the axis of the apparatus being level with

Archer introduced the third lens, M. Chevalier constructed something of the same kind for the late Mr. P. W. Fry, and subsequently M. Derogy adopted the same device for obtaining a sort of *multum in parvo* lens.

"About four or five years ago, Mr. Thomas Sutton, of Jersey, devised a form of lens which he called the 'symmetrical triplet,' which, as its name implies, consisted of one concave and two compound-convex combinations; the latter being exactly alike, and placed one at each end of the tube-mounting. The object aimed at was to correct the deviation of the pencils of rays, so that they should be incident and emerge in directions parallel to one another. Mr. Goddard, of Isleworth, then constructed some triple combinations, not adhering, however, to the symmetrical form, and subsequently M. Dallmeyer adopted the same principle of employing for landscape lenses three actinic combinations; these, however, were not mere copies of any of the preceding, but the formulæ for their construction were worked out quite independently by M. Dallmeyer, so that they only resembled the others in consisting of three parts, the central one being a concave lens.

"Somewhat later, Mr. Ross adopted a form of lens consisting of three parts, arranged as were the others; but here again the formulæ were calculated anew by Mr. Ross, and any person who will take the trouble of examining them will perceive at once that they differ in construction as much from those of M. Dallmeyer as the last-named optician's did from those of his predecessors."—*Trans.*

the wafer. You will remark that its image is round, even if you should move your ground-glass behind or in front of the focus, in which case the image only loses its sharpness. But turn the apparatus on its stand so that the image of the wafer comes as nearly as possible on the edge of the ground-glass. You will observe that it is now impossible to get a sharp image of it, and that, by moving your ground-glass in advance of or behind the focus, the image is lengthened in a vertical or horizontal direction.

Theoretical explanation of Astigmation.—Fig. 62 enables us to explain this result and to analyse its conse-

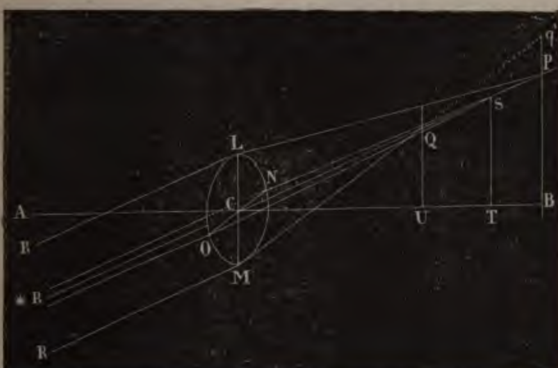


Fig. 62.

quences. Let L O M N be a convergent lens of which the principal axis is A B. Obliquely to this axis, let us take a radiating point R situated at infinity, and sending, consequently, parallel rays to the lens. Let us make a plane pass through the axis A B and the point R, which will cut the lens along its diameter L M; and let us suppose a second plane to pass through the point R perpendicular to the former one, the line of which on the lens will be the diameter N O; let us see the course of the rays emitted by the point R along these two planes, beginning with the first.

Let us draw, *firstly, the ray* R C passing through the optical

centre of the lens, which undergoes no deviation by refraction at the curved surfaces of the lens, and which prolonged, therefore, will constitute a secondary axis, R P. Let us draw to the two extremities of the diameter L M of the lens the incident rays R L and R M, which after refraction will cut the axis at Q and at P, just as we have seen in the chapter on spherical aberration. But, if the lens has a small aperture, the point of meeting will be sensibly the point Q.

In the plane R N O, which contains also the secondary axis R P, the incident rays R N and R O are symmetrical in relation to the secondary axis, as after refraction they cut the axis at the same point, S.

It is seen, therefore, that there are *two focal lengths* of the same lens for rays oblique to the axis, falling parallel to each other on the surface of a lens; the one in the plane passing through the principal axis of the lens and the radiating point: the other in the plane passing through the radiating point and the optical centre, and perpendicular to the first. This is what constitutes astigmation.

Reduction of Astigmation to the minimum.—Astigmation (that is, the difference between the primary focus and the secondary one) is reduced *to the minimum;* firstly, by means of the diaphragm, which divides the surface of the objective into many separate surfaces, each of which acts on radiating points of a different incidence; secondly, by making the spherical surfaces such that the immergent and emergent rays may make a very small angle with the normals to the spherical surfaces of the lenses.

Calculation of the Primary Focus and Secondary Focus.—We shall consider the most simple case, that of a simple lens, plano-convex, and furnished with a diaphragm with very narrow aperture, placed at the optical centre of the lens. We suppose the radiating point situated at infinity, and the bundle of parallel rays to be falling on the plane face *of the lens.*

Let C F (fig. 1, plate I.) be the axis of the lens, A a the axis of the luminous beam after refraction at the plane surface of the lens. Let us make a plane pass through these axes, and let $a\,b$ be an arc of a circle having its centre at C, representing the section of the convex surface of the lens by this plane. Let us consider in this a second ray, B b, of the beam: the two rays A a, B b, will emerge along a V and b V, and their point of intersection, V, will be approximately, and when the two rays are infinitely close will be exactly, the *primary focus.*

Let us calculate the distance a V as a function of the radius, C $a = r$, of the lens, and make the angles

$$\begin{aligned} \mathrm{V}a\mathrm{F} &= \theta \\ \mathrm{A}'a\mathrm{F} &= \eta \\ b\mathrm{C}a &= \phi \\ b\mathrm{V}a &= \psi. \end{aligned}$$

The triangle Vab gives

$$\mathrm{V}a : ba :: \sin \mathrm{V}ba : \sin \psi$$

$$\mathrm{V}a = ba \frac{\sin \mathrm{V}ba}{\sin \psi}.$$

Let us calculate each of the factors which enter into this expression. On letting C p fall perpendicularly on the chord $a\,b$, the triangle C $p\,b$ gives

$$ba = 2pb = 2\mathrm{C}b \sin \frac{\phi}{2} = 2r \sin \frac{\phi}{2}.$$

Let us call K the point of intersection of the ray V b, prolonged, with the axis a C. The angle V $b\,a$ considered as exterior to the triangle K $b\,a$ is equal to the sum of the opposite interior angles,

$$\mathrm{V}ba = \mathrm{VK}a + ba\mathrm{C}.$$

But the triangle V K a gives similarly

$$\mathrm{VK}a = \mathrm{V}a\mathrm{F} - \mathrm{KV}a = \theta - \psi,$$

and the right-angled triangle Cpa gives—

$$baC = 90^\circ - \frac{\phi}{2}.$$

By addition we find

$$Vba = \theta - \psi + 90^\circ - \frac{\phi}{2},$$

whence

$$\sin Vba = \sin\left[90^\circ - \left(\psi + \frac{\phi}{2} - \theta\right)\right] = \cos\left(\psi + \frac{\phi}{2} - \theta\right).$$

By substituting this in the value of Va, the latter becomes

$$Va = 2r\,\frac{\sin\frac{\phi}{2}\cos\left(\psi + \frac{\phi}{2} - \theta\right)}{\sin\psi}.$$

Let us observe now, that the angles ψ and ϕ are infinitely small, since the rays Aa and Bb are infinitely close. We have, thererefore,

$$\frac{\sin\frac{\phi}{2}}{\sin\psi} = \frac{\frac{\phi}{2}}{\psi} = \frac{\phi}{2\psi}.$$

Again, by developing the case of the difference of the arcs $\psi + \frac{\phi}{2}$ and θ, by means of the general formula,

$$\cos(a-b) = \cos a \sin b + \sin a \sin b,$$

we get

$$\cos\left(\psi + \frac{\phi}{2} - \theta\right) = \cos\theta\cos\left(\frac{\phi}{2} + \psi\right) + \sin\theta\sin\left(\frac{\phi}{2} + \psi\right),$$

whence, by observing that the arc $\frac{\phi}{2} + \psi$ being infinitely small, we can substitute it for its sine, and make its cosine equal to 1:

$$\cos\left(\psi + \frac{\phi}{2} - \theta\right) = \cos\theta + \left(\frac{\phi}{2} + \psi\right)\sin\theta.$$

We get, therefore,

$$Va = r\frac{\phi}{\psi}\left[\cos\theta + \left(\frac{\phi}{2} + \psi\right)\sin\theta\right].$$

Because of the smallness of the angles ϕ and ψ, the second term within the bracket may be neglected against $\cos\theta$, and there remains simply

$$\mathrm{V}a = r\,\frac{\phi\cos\theta}{\psi}.$$

There remains only therefore for calculation the ratio $\dfrac{\phi}{\psi}$.

Prolong B b and A a respectively to b B′ and a A′. If we observe that at the point b the luminous ray passes from one medium into another less dense, and that the angle of incidence is $\mathrm{C}b\mathrm{B} = \mathrm{E}b\mathrm{B}'$, and the angle of refraction V b E, we shall have, supposing n to be the angle of refraction—

$$\sin \mathrm{V}b\mathrm{E} = n \sin \mathrm{E}b\mathrm{B}'.$$

But

$$\mathrm{V}b\mathrm{E} = \mathrm{C}b\mathrm{K} = \mathrm{VK}a - \phi = \theta - \psi - \phi$$

and

$$\mathrm{E}b\mathrm{B}' = \mathrm{C}b\mathrm{L} = \mathrm{B}'\mathrm{LF} - \phi = \mathrm{A}'a\mathrm{F} - \phi = \eta - \phi.$$

Therefore

$$\sin[\theta - (\phi + \psi)] = n\sin(\eta - \phi),$$

but, because of the general formula

$$\sin(a - b) = \sin a\cos b - \sin b\cos a,$$

we have

$$\sin[\theta - (\phi + \psi)] = \sin\theta\cos(\phi + \psi) - \cos\theta\sin(\phi + \psi)$$

$$\sin(\eta - \phi) = \sin\eta\cos\phi - \sin\phi\cos\eta.$$

The angles ϕ and ψ being infinitely small, these formulæ are reduced to

$$\sin[\theta - (\phi - \psi)] = \sin\theta - (\phi + \psi)\cos\theta$$

$$\sin(\eta - \phi) = \sin\eta - \phi\cos\eta,$$

and by substitution of the latter values we get

$$\sin\theta - (\phi + \psi)\cos\theta = n(\sin\eta - \phi\cos\eta).$$

Again, the refraction at a gives similarly

$$\sin \theta = n \sin \eta ; \quad . \; . \; . \; . \; . \; (1),$$

which reduces the preceding relation to

$$(\phi + \psi) \cos \theta = n \phi \cos \eta .$$

Whence we derive

$$\frac{\phi}{\psi} = \frac{\cos \theta}{n \cos \eta - \cos \theta},$$

which, by substituting it in the value for Va, gives

$$\mathrm{V}a = r \frac{\cos^2 \theta}{n \cos \eta - \cos \theta} \quad . \; . \; . \; . \; . \; (2).$$

This value can be also put in another form by replacing n by $\frac{\sin \theta}{\sin \eta}$; it then becomes

$$\mathrm{V}a = r \frac{\cos^2 \theta \sin \eta}{\sin \theta \cos \eta - \sin \eta \cos \theta}$$

or

$$\mathrm{V}a = r \frac{\cos^2 \theta \sin \eta}{\sin (\theta - \eta)} \quad . \; . \; . \; . \; . \; (3).$$

If the direction of the axis of the incident pencil A a—that is, if the angle η—is made to vary, formula (1) will give the angle θ which fixes the direction of the emergent beam a V: the position of the *primary focus* V will then be known by formula (2). If we make $\eta = o$, the luminous beam becomes parallel to the axis of the lens, and the primary focus coincides with the principal focus F. Formula (2) then gives (by observing that $\eta = \theta = o$, whence $\cos \eta = \cos \theta = 1$),

$$\mathrm{F} = \frac{r}{n - 1}.$$

Hence the relation

$$\frac{\mathrm{V}a}{\mathrm{F}} = \frac{\cos^2 \theta \, (n - 1)}{n \cos \eta - \cos \theta}.$$

This relation between V a and θ is the polar equation of the curve V F formed of all the primary foci, and makes the curvature of the field of the lens known in so far as these foci only are considered.

But this curve differs from that of the *secondary foci*, H F, which we have still to determine.

Let us consider, at a, a section passing through the axis of the lens and perpendicular to $a\,b$, and let us suppose that this section is the arc of the circle $a\,m$. If a luminous ray M m be infinitely close to the axis A a of the beam, it will cut the refracted ray in a V at a point H different from V, and it is this point H which we have called the *secondary focus.*

Take M′ m' and M m equidistant from A a; the refracted rays are m' H, m H. The plane M m H contains the radius of curvature C m, normal to the point m, and the plane M′ m' H contains also the radius C m'. Since these two planes pass through C, their intersection passes, therefore, through the same point, and is no other than the right line C H. But as each of these planes contains a parallel to the incident rays, their intersection C H is likewise a parallel to these rays. Therefore C H is parallel to A a, and the angle H C $a = \eta$ (fig. 2, Pl. I.)

The triangle H a C gives

$$\frac{a\,\mathrm{H}}{\mathrm{C\,H}} = \frac{\sin \mathrm{H\,C}\,a}{\sin \mathrm{C}\,a\,\mathrm{H}} = \frac{\sin \eta}{\sin \theta} = \frac{1}{n}.$$

The curve H F of the secondary foci is therefore such that the ratio of the distances H a, H C, from any one of its points to two fixed points a and C, is a constant $\frac{1}{n}$, and it is easy to demonstrate that such a curve is a circle.

Let C and a be the two fixed points, and H any point whatever on the curve. Take the points B and D such that we have—

$$\frac{a\,\mathrm{B}}{\mathrm{B\,C}} = \frac{1}{n} \text{ and } \frac{a\,\mathrm{D}}{\mathrm{C\,D}} = \frac{1}{n}.$$

From the definition of the curve, this will pass through the two points B and D.

Let us join B H and D H. The proportions are

$$\frac{a\mathrm{H}}{\mathrm{CH}} = \frac{a\mathrm{B}}{\mathrm{CB}} \text{ and } \frac{a\mathrm{H}}{\mathrm{CH}} = \frac{a\mathrm{D}}{\mathrm{CD}}.$$

The first shows us that B H is the bisector of the angle C H a, and the second that H D is the bisector of the supplementary angle a H K. These two right lines H B and H D are therefore perpendicular to each other, and the curve possesses the property, that all inscribed angles, such as B H D, are right angles. It is therefore the circumference of a circle.

Let us observe now that from the proportion

$$\mathrm{CB} : \mathrm{B}a :: n : 1$$

we derive

$$\mathrm{CB} + \mathrm{B}a : \mathrm{B}a :: n + 1 : 1, \text{ or } \mathrm{B}a = \frac{\mathrm{C}a}{n+1} = \frac{r}{n+1}.$$

Similarly, the proportion

$$\mathrm{CD} : a\mathrm{D} :: n : 1$$

gives

$$\mathrm{CD} - a\mathrm{D} : a\mathrm{D} :: n - 1 : 1, \text{ or } a\mathrm{D} = \frac{\mathrm{CD} - a\mathrm{D}}{n-1} = \frac{r}{n-1};$$

by adding these equations together we get

$$\mathrm{B}a + a\mathrm{D} = \mathrm{BD} = \frac{r}{n+1} + \frac{r}{n-1} = \frac{2rn}{n^2 - 1}.$$

Now, B D is the diameter of the circle B H D; therefore, indicating the radius of the circle by R, we have

$$\mathrm{R} = \frac{nr}{n^2 - 1}.$$

When the ray a H falls on the axis a D, the secondary

focus H forms at D, which is consequently no other than the principal focus, F; and, in fact, we have found above:

$$a\mathrm{D} = \frac{r}{n-1} = \mathrm{F}.$$

To find now the value of a H, let us observe that the triangle C H a gives

$$a\mathrm{H} : \mathrm{C}a :: \sin\eta : \sin(\theta - \eta),$$

whence

$$a\mathrm{H} = \frac{r \sin\eta}{\sin(\theta - \eta)}.$$

By comparing this with formula (3) we shall have finally for the ratios of the primary and secondary focal lengths which correspond to a given angle θ

$$\frac{\mathrm{V}a}{a\mathrm{H}} = \cos^2\theta.$$

To obtain the distance of these foci we deduce from the above proportion

$$\frac{a\mathrm{H} - a\mathrm{V}}{a\mathrm{H}} = \frac{1 - \cos^2\theta}{1} = \sin^2\theta$$

$$\mathrm{VH} = \sin^2\theta \times a\mathrm{H} = \frac{r \sin\eta \sin^2\theta}{\sin(\theta - \eta)}.$$

This formula shows that astigmation is as much more considerable as the beam of incident rays is more inclined to the axis.

CHAPTER VI.

DESCRIPTION OF PHOTOGRAPHIC OBJECTIVES.*

Division of Objectives into non-aplanatic and aplanatic.—We have seen (p. 75) that spherical aberration might serve to divide photographic objectives into two great classes—the one consisting of *non-aplanatic* objectives, which only give sharp images on the condition of being furnished with a very small diaphragm; the other of *aplanatic* objectives, which give with their entire aperture sharp images, but on a focal plane of less extent than those given by objectives of the first class. We shall adopt, then, this division in the present chapter.

The differences which characterise these two kinds of objectives are as follow:—

Aplanatic objectives are particularly suitable for the reproduction of animated scenes, because, as they are capable of being used with their entire aperture, they allow of the exposure to light being but short. They only cover sharply a focal plane of which the greatest side is, at the most, half their focal length; but if furnished with a diaphragm, the extent of sharpness of image is increased.

With a diaphragm extremely small, $\frac{f}{30}$, they cover a surface almost as great as *non-aplanatic* objectives, and then

* NOTICE.—To avoid repetitions, we shall always indicate the focal length of the objective by f, and the aperture of the diaphragm by the fractions $\frac{f}{30}$, $\frac{f}{40}$, $\frac{f}{60}$, &c., which express apertures of the thirtieth, fortieth, sixtieth, &c., of the focal length.

Numerical data will always be expressed as a function of the focal length of the objective employed, which is the only way of comparing different objectives together.

they are suited for the reproduction of buildings, landscapes, &c.

Non-aplanatic objectives employed with all their aperture give confused images over the whole extent of the focal plane. With a diaphragm equal to $\frac{f}{10}$, the image begins to assume sharpness, but still not of a very marked character. It is only when the diaphragm is but $\frac{f}{30}$, $\frac{f}{40}$, and even $\frac{f}{60}$, that the image acquires perfect definition. These objectives are therefore *very slow* in impressing photographic surfaces; but their focal plane is much greater than that of non-aplanatic objectives. They are for the most part (the single combination excepted) free from distortion and astigmation, whilst among aplanatic objectives the triplet alone is free from distortion.

As, on the whole, the only advantage of *non-aplanatic* objectives consists in the large angle which they embrace; as the *triplet*, without including so great an angle, yet includes one sufficient in practice; and as, moreover, it can give sharp images with much larger diaphragms—and even with its full aperture, when the non-aplanatic objective no longer gives images at all—the advantage rests with the triplet, which, in the actual state of optical science, is the best objective there is. But in the preface to this volume the reader will find our opinion more fully justified in this respect.

SECTION I.—*Non-aplanatic objectives.*

Single (Landscape) Objective.—Jean Baptiste Porta, the inventor of the camera obscura, employed, as objective, a plano-convex lens of crown-glass, of which the convex face was towards the ground-glass, and which was reduced to its central part by a diaphragm in contact with it, of which the diameter was from $\frac{f}{20}$ to $\frac{f}{30}$. Under these conditions, the field of the image was very curved, as we have explained,

page 84. It resulted from this, that to obtain a focal plane quite defined in all its parts, the greater side of the image could not be more than $\frac{f}{5}$. Nevertheless such an arrangement was almost free from distortion.

If the diaphragm be moved away from the lens, the field becomes flatter, but the distortion increases, since the lens is now under the conditions represented in fig. 54, and explained at page 97.

Opticians soon found out that a concavo-convex meniscus, substituted for the plano-convex objective of Porta, gave, with equal focal length, a well-defined image of much greater extent. The concave surface was towards the object to be reproduced, and the convex surface towards the ground-glass. The focal plane was covered with sharpness over a square surface, the diagonal of which was equal to $\frac{f}{4}$. The aperture of the diaphragm was $\frac{f}{30}$, and its distance from the lens $\frac{f}{5}$.

Such then was the simple objective at the time of the discovery of the daguerreotype in 1839, and it served to produce the first proofs by this process. But it was soon found out that the image, when sharp on the ground-glass, was not so on the photographic surface; that, in a word, the lens possessed a chemical focus depending on the angle of dispersion of the glass of which it was made. For the visual focus, corresponding to the yellow rays, differed considerably from that of the blue and violet rays, which was nearer, and which constituted the chemical focus. It became necessary, therefore, to graduate the base of the camera, according to the conjugate focus of the lens, and this was a long and difficult operation, so that opticians were appealed to on all sides to obtain objectives free from this chemical focus.

The first objectives of this nature appear to have been constructed by the late *Charles Chevalier*. This optician made use of the achromatised objective of an opera-glass—an objective

formed of a bi-convex lens of crown-glass cemented to a plano-concave lens of flint-glass. Employed with its convex face turned towards the object to be reproduced, the image had a remarkable sharpness and brilliance, since in this position the lens could be employed with all its aperture, spherical and chromatic aberration being corrected in it along its axis. But the extent of the focal plane was very trifling, and at the most its greater side was but $\frac{f}{8}$. *Charles Chevalier* did as opticians before him; he turned the lens, so that its convex face was now towards the ground-glass. In this position the image was much less sharp than in the preceding case, but he furnished it with a diaphragm placed in front of the objective, so that the definition was thus considerably augmented, at the same time that the field of the image was much flattened, to such an extent that the greater side of the focal plane, sharply covered, now became $\frac{f}{3}$.

Fig. 3, plate I., represents the primitive single objective. The achromatic plano-convex lens, A, was placed in a conical mounting of brass, C, furnished with a diaphragm, B, beyond which a circular plate slided, which served as a shutter.

The aperture of the smallest diaphragm was generally $\frac{f}{30}$. There were, besides, several others—of which the greatest had an aperture four times as great as that of the first, $\frac{f}{15}$, which could be substituted for this, according to the intensity the image was desired to have.

The objective was mounted on a camera, F N O F′, of which the ground-glass, F F′, was much smaller than the field, G G′—an inevitable consequence of the too short distance between the lens, A, and the diaphragm, B. The objective only acted, therefore, at its central part, and there was thus lost *the half* of its diameter, as is well shown in the figure. The spherical aberration for rays oblique to the axis and the distortion were thus reduced *to a less amount* than if the diaphragm

had been situated farther in front, and the field was also nearly flat, because the plano-convex form was not the best that could have been chosen; but at this period opticians were not so skilful as they are at present.

The plano-convex form is therefore the first which was given to the single objective. Some opticians afterwards discovered that the meniscus form was preferable to the plano-convex. The radius of curvature of the concave face, which looked towards the object to be reproduced, was generally, and is still, from $\frac{f}{3}$ to $\frac{f}{2}$, the diameter of the objective being $\frac{f}{6}$.*

* When the face of the lens is thus chosen, the radius of curvature of the two surfaces in contact is determined by calculation, and then that of the face which is towards the ground-glass.

Let F be the focal length of the two lenses cemented together; n_v the index of refraction of the crown-glass (bi-convex); n'_v the index of refraction of the flint-glass (bi-concave); Δ the ratio of the dispersive powers; and R the radius of curvature, arbitrarily chosen, of the concave face of the flint-glass, which looks towards the object to be reproduced. We shall find the other data of the system—namely, R′ the radius of curvature of the two surfaces in contact of the crown and flint glass; R″ the radius of curvature of the face of the crown-glass which is towards the ground-glass; f the focal length (negative) of the flint-glass lens; and f' the focal length (positive) of the crown-glass lens, by the following equations:—

$$\frac{1}{f} + \frac{1}{f'} = \frac{1}{F} \quad . \quad . \quad . \quad . \quad (1)$$

$$\frac{1}{f'} = - \Delta \quad . \quad . \quad . \quad . \quad (2)$$

$$\frac{1}{f'} = (n_v - 1)\left(\frac{1}{R} - \frac{1}{R'}\right) \quad . \quad . \quad . \quad . \quad (3)$$

$$\frac{f}{f'} = (n'_v - 1)\left(\frac{1}{R'} - \frac{1}{R''}\right) \quad . \quad . \quad . \quad . \quad (4).$$

If, by the photographic test, this lens is found to possess a chemical focus, it is because Δ has not been accurately calculated. Then, if this focus falls *in advance* of the visual focus, substitute for the face of the flint-glass, of which R is the radius of curvature, another face of which the radius of curvature is *shorter;* and the contrary if the chemical focus fall behind the visual focus. We shall see, in the following chapter, how the chemical focus is found to fall in front of or behind the visual focus.

The form of the single objective which is therefore generally adopted is represented by fig. 4, pl. I., the *concave face of flint-glass* being towards the object to be reproduced, the *convex face of crown-glass* towards the ground-glass. As to its diameter and the position of the diaphragm, these elements depend entirely on the greater or less concavity of the flint-glass face. If a large diameter relatively to its focal length, *a b*, is given to the lens A, (fig. 5, pl. I.), the diaphragm, D, must be placed at a greater distance from the lens, and such that the circle, M N O, which bounds the focal plane nearly circumscribes the rectangle, *c d e f*, which represents the size of the image for which the objective is constructed. In this case, if the radii of curvature of the objective are suitably chosen, the field is as flat as it can be, but the distortion is considerable.

If the diaphragm is moved back to the lens—which, for the same size, *c d e f*, of image, is thereby reduced to a central part of its primitive surface (as is shown in fig. 5, pl. I.)—the field becomes less flat, but the distortion diminishes. In this case, in order that it may be found in the best possible conditions for sharpness, a more concave face must be substituted for the existing face of flint-glass (the one towards the object to be reproduced). The greater, therefore, the diameter of the single objective, the focal length remaining the same, the more ought the flint surface facing the object to approach to a plane, and then the more considerable becomes the distortion, but the flatter the field; the less the diameter, the more concave this face becomes, and the smaller is the distortion—within, of course, the limits which have been determined by practice with an approximation sufficient for the guidance of the optician.

In every case the spherical aberration is corrected by the employment of a very small diaphragm, $\frac{f}{30}$, and the chromatic completely so by a proper choice of the flint and crown glasses; but it is of great importance to render the spherical aberration as slight as possible, for the following reason.

There is required in a photographic proof a very great perfection in the details, which constitutes its sharpness. Now, we have seen, in the chapter on spherical aberration, that its effect was to destroy this definition over the whole extent of the image; and that, to avoid this defect, it was necessary to correct the aberration as much as possible, which was done in the single objective by means of the diaphragm. But the more considerable this aberration is, the smaller must the diaphragm be to give the image that definition which is required of it, and the longer therefore must be the exposure to light, since the intensity of the image necessarily depends on the aperture of the diaphragm. It is therefore of very great importance that the spherical aberration should be reduced in the single objective to the lowest possible degree, because it will then be possible to make use of a larger diaphragm.

As to the spherical aberration, if the optician correct it for pencils parallel to the axis of the objective, he cannot correct it for pencils oblique to it; and we have seen that, to reduce this aberration to the minimum, the angles of immergence and emergence of the pencils ought to form equal angles with the section of the lens traversed by these pencils, which could only be effected with meniscuses, the concave face of which was of a relatively short radius of curvature.

To attain this end, some opticians of great merit have adopted a new form of single objective (fig. 4 bis, pl. I.), in which the *crown-glass* lens, B, of meniscus form, has its concave face towards the object to be reproduced.* The divergent flint-glass lens, A, is cemented to the crown-glass lens, and has the same diameter. Its form is also a meniscus. The arrangement is therefore the reverse of that of the old objective, represented in fig. 4, pl. I., in which the flint-glass, B, is turned towards

* Mr. Grubb, of Dublin, several years ago patented this form of single combination for photographic work, and we believe it is now used by other opticians. A modification of the same system forms one of the components of Mr. Ross's doublet, and was used in double combinations, and also as a *single objective*, by the late Mr. Ross, nearly twenty-five years ago.—*Trans.*

the object to be reproduced, whilst in this it is the crown-glass. The first end now served by the flint-glass lens is to achromatise the combination for pencils parallel to the axis, and the second to increase the focal length of the combination for incident pencils oblique to the axis and emergent from the crown-glass lens, so as to give a focal plane very flat, and of much greater extent than that obtained with the old objective. The flint-glass lens, if the concave face of the crown-glass lens be well chosen, also renders the value of the spherical aberration much less than it is with the old single objective, which permits the use of larger diaphragms. The objective is thus more rapid (photographically speaking); and, further, the image is more brilliant, and possesses more relief, as we have stated at page 92.

Lastly, this objective having for the same extent of image a focal length shorter than that of thé old objective, possesses therefore over the latter all advantages possible.

There are therefore two kinds of single objectives—the first, that in which the flint-glass faces the object to be reproduced; the second, that in which the crown-glass is turned towards this object. Both have the meniscus form, and in both the concave face is towards the object to be reproduced, and the convex one towards the ground-glass; but the latter has over the former the advantages of less distortion, a shorter focal length, a greater rapidity, and a smaller bulk.

The old form—the one not so good—is still generally adopted by French and German opticians, several of whom, however, begin to adopt the other. The new form is adopted by English and American opticians.

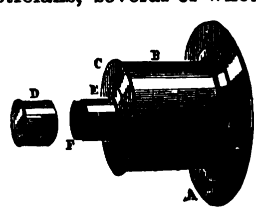


Fig. 63.

Fig. 63 represents the mounting of the single objective adopted in France. The flange A is fixed on the camera by means of screws. The tube B contains, in the plane of the flange A, the objective.

At C this tube is terminated by a circular disc, perforated at its central part; to which is adapted the small tube E, which contains the brass diaphragms, which a cylinder, F, of blackened brass keeps in place. D is the cap.

To change the aperture of the diaphragm, the ring F must be removed, but this is inconvenient.

The English and Americans have adopted as a mounting the form sketched in fig. 64. A A' is the flange which is fixed on the camera, and B C, D E, the cylindrical tube in which the objective, L M, is mounted. F G is a disc of brass pierced with circular apertures, the centres of which are at equal distances from its centre of rotation. It is sufficient therefore, in order to substitute one diaphragm for another, to rotate the disc by sliding the finger on its exterior part F. We shall describe, however, this method more at length at page 125.

The following are the dimensions of the single objectives adopted by French and English opticians:—

The *diameter* of the *English* objective* is generally the *fifth* of its focal length, and the greater side of the image is equal to *two-thirds* of this focal length.

The *diameter* of the *French* objective is generally the *seventh* of its focal length, and the longer side of the image sharply covered is *half* this focal length.

The French objective has less distortion than the English objective, taking as the term of comparison the size of the image; but it has more, if we take for the term of comparison the focal length of the objective.

M. Dallmeyer's new single Objective.—With the object of reducing the distortion to as slight an amount as possible, and of making the objective include a maximum of angle, M. Dallmeyer has sought to give to the single objective a meniscus form more pronounced, and has brought the diaphragm considerably nearer to the lens. If he had

* It is to be understood that we speak here of the objectives coming from workshops of the first order, such as those of Messrs. Ross and *Dallmeyer.*

adopted the form of objective already existing, he would have been able to attain his end by sacrificing sharpness at the margins of the image; but taking as an essential condition the maintaining the image as sharp at the margins as at the centre, he has had to adopt another optical combination, which is represented by fig. 64.

Instead of two lenses, the first of crown-glass, the second of flint, M. Dallmeyer employs an additional one of crown-glass, the index of refraction of which is slightly different from that of the crown-glass of the first one.

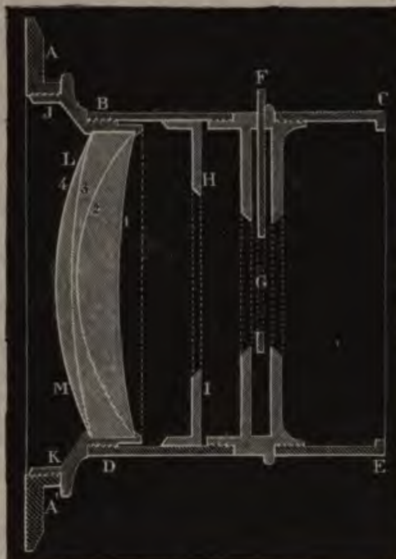


Fig. 64.

This figure represents *with very great exactitude* the objective and its mounting of the actual size, the focal length of the objective being 6·95 inches, and its diameter 1·6. These are the other data of the system, expressed in terms of the focal length:

Diameter of the lenses		2302
First lens	$-r^1$	6043
(crown-glass$_1$)	$+r^2$	1727
Second lens	$-r^3$	1727
(flint-glass)	$+r^4$	4813
Third lens	$-r^5$	4813
(crown-glass$_2$)	$+r^6$	2561
Focal length of the combination		10,000
Index of refraction (yellow) of the flint-glass		1581
" "	crown-glass$_1$	1521
" "	crown-glass$_2$	1514

Ratio of the focal lengths to produce achromatism:

$$\text{Crown}_1 \text{ and flint-glass } \frac{f}{f'} = 0{\cdot}706$$

$$\text{Crown}_2 \text{ and flint-glass } \frac{f}{f'} = 0{\cdot}645$$

We here seize the opportunity of publicly thanking M. Dallmeyer for having given us the drawing and numerical data relating to his single objective, Petzval's objective, and his own triplet, by which we have been saved the long and difficult work of determining them experimentally.

The three lenses are therefore meniscuses joined together, and form a single combination, the concavity of which is turned towards the object to be reproduced, precisely as in the ordinary single objective.

The diaphragm is placed in front of the lens, at a distance equal to the diameter of the lens, to which, therefore, it is much nearer than usual. The aperture of the smallest diaphragm is $\frac{f}{30}$.

The following are the principal advantages of M. Dallmeyer's single objective.

With a diaphragm of $\frac{f}{20}$, it covers with *perfect sharpness* a circular focal plane 72° in extent; with a diaphragm of $\frac{f}{30}$, a circle of from 85° to 90°. The field of the objective is therefore enormous, since the longer side of the image (which, as we know, is always rectangular), is greater than the focal length of the objective, while, in the best single combinations previously constructed, this side was at the most but two-thirds of the focal length.

This has, in the reproduction of landscapes, a considerable advantage in an artistic point of view, which is, that the foregrounds are represented in the image, and thus give to the more distant planes an astonishing effect of perspective. It was not thus with the old objectives, the field of which was of much less extent.

The distortion is, for an image of which the greater side is equal to the focal length of the objective, reduced to a small quantity, the diameter of the objective being relatively less than that of the old objective. Besides, the single objective being destined solely for landscapes, the distortion causes no visible defect in the image.

The chemical focus for pencils oblique to the axis is reduced to a less quantity (see page 82); the field is flatter than that of the old single objective; and, lastly, the image is brighter.*

* We have seen that a refracting plate *reflects* a part of the light incident *upon it.* Now, it frequently happens in optical arrangements that the sur-

The new single objective of M. Dallmeyer has, finally, as a last advantage, that of being less in respect of weight and bulk, and of requiring, on account of its short focal length, a much shorter camera, which is, in practice, a very great one.

To terminate this article, we have to examine in what circumstances the single objective is to be prefered to the other systems.

Like all the non-aplanatic objectives, the single lens having to be furnished with a very small diaphragm (one-thirtieth of the focal length), in order to give sharp images, cannot serve for the reproduction of groups, animated landscapes, and portraits, except by having at command a bright light like that of the sun, which generally produces effects but little artistic. The *triplet* is in this case infinitely preferable to it, since, with a diaphragm of double the diameter of the other (one, consequently, four times more rapid), it gives images perfectly sharp, the greater side of which is $\frac{f}{2}$. The single lens not being free from distortion, seeing that it distorts images in the way shown in fig. 56, page 98, cannot be employed for the reproduction of buildings, maps, and in general all objects in which straight lines occur. In this case, again, the *triplet* is preferable to it.

On the other hand, the single lens is superior to the triplet for the reproduction of landscapes, because, with equal diaphragm, it is rather more rapid: firstly, because it offers fewer optical surfaces; secondly, because the incident and refracted pencils are almost normals to the refracting

faces of the lenses which form them, acting as reflectors, throw over the image furnished by transmission a diffused light, which tends to fog the image, and which often betrays itself by a very luminous spot at the centre of the ground-glass, particularly if the sky of the landscape occupies a great extent of the image. In M. Dallmeyer's objective the transmitted and reflected rays are nearly normals to the surfaces, so that the image is free from this fogginess, and consequently is more brilliant.

surfaces (on account of its meniscus form). But in this respect it is inferior to the globe-lens.

The single lens possesses greater depth of focus (see page 85), than the triplet, and, generally, than all known objectives except the orthoscopic.

On the other hand, it covers a smaller angle than the *globe*, the *periscopic*, and the *orthoscopic objectives*.

It is seen, therefore, that the single objective presents, when compared with other objectives, more disadvantages than advantages. Thus the triplet is preferable to it as regards the absence of distortion, and the power of reproducing animated landscapes; and the *globe*, the *periscopic*, and the *orthoscopic objectives* are preferable to it as regards the extent of the field. But as, in general, landscapes require a very long exposure to light, and as the extent of the field need not be great for this kind of photography, the triplet, on the whole, is for the reproduction of landscapes, especially animated ones, *practically* (if not scientifically) preferable to the single objective, even to the new one of M. Dallmeyer, of which we shall speak presently, which has over the triplet but one advantage, that of including a larger angle.

The Globe-objective or Globe-lens.—This objective, invented by Messrs. Harrison and Schnitzer of New York, and represented by fig. 65, is formed of two achromatic and identical convergent meniscus lenses, the distance between which is such that the external surface of the meniscus lenses prolonged forms one and the same sphere, hence the name of *globe-lens* or *globe-objective*.

The figure shows how the globe-lens is mounted. The two meniscus lenses, each enclosed in a ring, are fixed to the extremities of a brass tube, terminated on the side towards the object to be reproduced by an expanded cone of blackened brass, on which is fitted the cap of pasteboard which serves to close it.

At the middle of the mounting of the objective is the diaphragm, which is represented separately, at the side of

the figure. It consists of a circular plate of brass, which passes out beyond the mounting, and which is perforated by

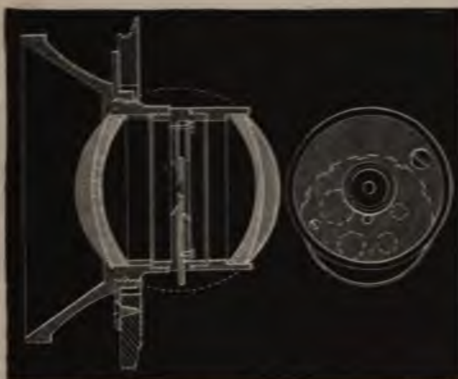


Fig. 65.

Radius of curvature of the 1st surface of crown-glass	1412
" 2nd " "	2403
" 3rd " flint-glass	2403
" 4th " "	1620
Diameter of the lenses	1875
Thickness of the meniscus (at its central part)	231·5
Distance, measured along the axis, between the external surfaces	2824
Absolute focal length	10,000
Aperture of the largest diaphragm $\frac{f}{36}$	= 277·7
" smallest " $\frac{f}{72}$	= 138·8

Density of the crown-glass 2·543 ($n'_H = 1{\cdot}53$)
" flint-glass 3·202 ($n'_H = 1{\cdot}60$)

The two flint and crown glass lenses are cemented together. The two achromatic meniscuses are equal to each other. The diaphragms are situated at equal distances from the two meniscuses.

These data have been communicated to us by Messrs. *Gasc* and *Charconnet*, of Paris, the opticians who introduced the globe-objective into France under the name of *lentiforme de l'œil*; and who construct it with great perfection, and at a price much lower than the original American objectives.

holes which constitute the diaphragms properly so called. This disc revolves about a centre placed above the axis of the objective, and the holes which constitute the diaphragms are all at equal distance from this centre. The disc turns,

with gentle friction, between two circular plates perforated at their central part. A spring acts on the disc, and catches by its extremity in shallow notches, so that when we turn the disc from the outside of the objective, a shock is felt each time that the aperture of the diaphragm corresponds with the axis of the objective.

In the objective that we have before us, the apertures of the diaphragms are such that the times of exposure are respectively from the greater to the less, 1, 2, 3, 4, 5, that is, that the smallest diaphragm (No. 5) requires five times as much exposure as the largest, of which the aperture is 1; the next (No. 2), twice as long; No. 3, three times, and so on. The objective is screwed to a flange fixed on the front of the camera, a construction identical with those of other systems.

The mounting of the objective unscrews into three parts, as may be seen in the figure, which allows of the part which carries the diaphragm to be separated from those which carry the lenses. This is indispensable, for the purpose of cleaning the inner surface of the lenses.

Persons familiar with photographic optics will comprehend, on glancing at the numerical data enunciated above, the great originality of the globe-lens. The luminous pencils emitted by external objects, situated within or without the axis of the objective, strike normally the external surface of the meniscus which is towards them, emerge from the first meniscus, strike *almost* at the normal incidence the concave face of the second meniscus, and emerge from the entire system, forming with the axis an angle the same as that of their immergence. Hence a complete destruction of distortion, and an almost complete destruction of astigmation.

The flint-glass lenses only serve here for achromatism, but the choice of the outer surface of crown-glass is such, that these flint-glass lenses render the field flatter than if,

'egoing the destruction of the chemical focus, the objective ıre reduced to two simple convergent lenses having 1412 d 1620 as radii of curvature. The angle included by the jective is very considerable, and exceeds 75°, so that e length of the greater side of the focal plane sharply vered is greater than the focal length of the objective, hich has for its measure the distance of the principal focal ane from the diaphragm. The examination of some globe-nses has proved to us, that an objective of 10 centimètres cal length covers *sharply* a focal plane of 14 by 12 centi-ètres. In this respect, however, the globe-lens is inferior Mr. Ross's *doublet* and M. Steinheil's *periscope*; but it ssesses over the former the advantage of being perfectly e from distortion, and of being more rapid with equality of aphragm, and over the latter that of having its chemical d visual foci coincident.

In all these respects, therefore, the globe-lens would be a ecious objective for photographers, did it not possess an ceedingly great spherical aberration. Accordingly, the dia-ıragms fitted to the objective must be extremely small (not ss, however, than $\frac{f}{72}$, otherwise the phenomena of diffraction ould be produced in the image), never greater than $\frac{f}{36}$, else e image would be wanting in sharpness over the whole tent of the focal plane.

This necessity of using very small diaphragms has not ly the effect of rendering the objective very slow; this ould be only a defect quite remediable by increasing the me of exposure; but it has a more troublesome result, that giving images in which the foregrounds are but slightly veloped (are too black), and in which the horizons are *larised*, that is, have lost details, in consequence of too long exposure. In a word, the image is wanting in brilliancy d relief, and possesses these qualities only in the case where e subject to be reproduced offers a very large surface with-

out foreground, such as a panorama, a map, or an engraving. This defect is, besides, common to all the non-aplanatic objectives, and the only one which may form an exception is, perhaps, the single objective, and particularly that of M. Dallmeyer, the spherical aberration of both being much less than that of the globe-lens.

If the smallest diaphragm be employed, that of $\frac{f}{72}$, the image has very great sharpness, equal to that of aplanatic objectives. Further, in this case the depth of focus of the globe-lens is so considerable, that all objects situated at more than 70 times the focal length of the objective appear on the ground-glass of the camera perfectly defined. Moreover, the extent of the field is then very considerable, but, at the same time, the image is particularly deficient in that brilliancy which gives it its artistic value.

The employment of this objective is limited to the reproduction of buildings, landscapes, and especially maps and engravings. As it only gives fine proofs on the condition of being furnished with very small diaphragms, it cannot serve to reproduce animated landscapes. It is, therefore, limited to the reproduction of still nature; which may, without inconvenience, require a long exposure. It is always necessary to employ it with the smallest of the diaphragms it admits, in order to obtain a great sharpness of image over a considerable field. In reproducing a landscape or a building, very near foregrounds, which would come out too black, must be avoided, as well as very distant backgrounds, which would be confounded with the sky, and be wanting in details, for the reason we have stated above. The globe-lens (and the non-aplanatic objectives, the description of which follows) can never reproduce any landscape or view along with clouds. The power of doing this is confined to the objectives of which the diaphragm is at the most from $\frac{f}{20}$ to $\frac{f}{30}$, such as *the triplet*, the orthoscopic and the single objective.

Mr. Sutton's Panoramic Lens.—The necessity that exists of using curved glasses with this objective will always render its employment very limited, consequently we shall not devote much time to its description.

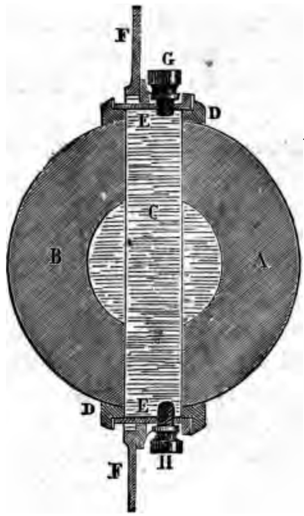


Fig. 66.

Fig. 66 represents a section of the lens. Two lenses of glass, A and B, with spherical curvatures, concavo-convex, are fixed in a metallic ring, E, which screws on a second flat flange, F, fixed on the camera. The hollow part, C, is filled with water. The surfaces of the glass lenses are concentric, the optical centre of the combination coinciding, therefore, with the centre of the figure. Achromatism is obtained by giving to the surfaces of the glass lenses the radii of curvature determined by calculation, which, for pure water and for glass having an index of refraction equal to 1·57, is as 1 to 2.

Such an objective possesses a considerable spherical aberration, and a very curved field. Let us see how Mr. Sutton removes these two imperfections. By introducing a diaphragm, of small aperture ($\frac{f}{30}$ to $\frac{f}{60}$) between the two glass lenses equally distant from each of them, the spherical aberration is completely destroyed, and the images possess great sharpness. But it is easy to conceive that the ground-glass would be unequally illuminated, inasmuch as, for rays parallel to the axis, the circular diaphragm would present an aperture greater than that for oblique rays, particularly such

very oblique ones as those which the lens is intended to include. Now, in place of a single diaphragm, Mr. Sutton takes two, which he places equally distant from the centre of the sphere which constitutes the objective and from the concave surfaces of the glass lenses; and he makes their aperture elliptical, the long axis of the aperture being in the *horizontal* direction, for he intends his lens to include *horizontally* a large angle, in other words, to take in *panoramic* views. There remains now the second difficulty, the curvature of the field. To correct this, Mr. Sutton diminishes in the *vertical* direction the dimension of his glass, and curves it in the *horizontal* direction. Hence it follows that the ground-glass, instead of being flat, is a portion of a cylinder. With these conditions the image obtained is, to the image that would be produced on a flat glass (or by a single objective of the same focal length), as 1 to 3. The horizontal angle included by the lens is 100°, and the vertical 30°.

Mr. Sutton's objective, like the globe-lens, is free from distortion. But this quality is of little importance, inasmuch as the objective is only intended for panoramic views, in which the effects of distortion are scarcely perceptible. On the other hand, it possesses, viewed in connection with the smallness of its diaphragm, the defects pertaining to the globe-lens; but these defects are here less evident, because panoramas do not generally present foregrounds, and because in all cases, if they did present such, the objective would not reproduce them, since the large angle which it includes is horizontal and not vertical. Further, since panoramas possess a considerable luminous power, the image possesses a greater brilliancy than the smallness of the diaphragm would lead us to expect.

The Periscope of M. A. de Steinheil.—This objective (fig. 67), which has only come to our knowledge while this work was in the press, through private letters from the inventor, is formed of two meniscus lenses of crown-glass, C E, D F, the concavities of which are identical and facing

each other. Half-way between the lenses are the diaphragms L L′.

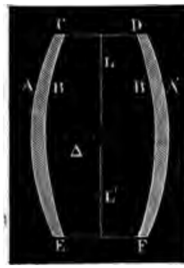


Fig. 67.

Diameter of the lenses	1256
Radius of curvature of the surfaces A and A′	+ 1753
,, ,, B and B′	— 2076
Δ or distance between the two lenses	1256·35 or 829
Thickness of the lenses measured along the axis	125·6
Index of refraction: n_o = 1·5233	
,, n_v = 1·5360	
Focal length of the system (visual focus) f_o	10·000
,, ,, (chemical focus) f_v	9·754
Aperture of the diaphragm $\frac{f}{40}$	251·3

This objective is the best which could be produced by means of two simple non-achromatised lenses. It possesses, indeed, a chemical focus which necessitates a rectification after each focussing; but this rectification is simple and easy, since the distance which it is necessary to advance the focal plane towards the lens is always the same fraction of the focal length, namely, $\frac{39}{40}$ or 975-thousandths of this length. Besides, the depth of focus of this objective is so considerable, that a slight error in this rectification would scarcely diminish the sharpness of the image.

The incident pencils, oblique or parallel to the axis, form with it the same angle on leaving the objective as on entering it. The optical centre of the compound system coincides therefore with the point in the figure situated on the axis half-way between the two lenses, where also is the diaphragm. It is thus in all the symmetrical doublets—for example in the globe-lens—and therefore the periscope is, like the globe, entirely free from *distortion.*

The field of the periscope is very flat (in other words, the image is rigorously sharp all over the surface of the ground-glass). Of all known objectives, it is the one of which the focal length is the shortest for the same extent of image sharply covered, since, with a diaphragm of an aperture of *from* $\frac{f}{60}$ *to* $\frac{f}{72}$, *it covers* an angle of 100°.

It is also the one of which the diameter is the least, as may be seen from the following table, which has been communicated to us by M. de Steinheil:—

Nos.	Diameter of the Lens in Millimètres.	Focal length of the Lens in Centimètres.	Size of the Image in Centimètres.
1	8·9	7·4	12 2
2	11·2	8·9	17·6
3	18·0	14·4	27·0
4	22·5	17·6	35·2
5	33·8	35·2	56·8
6	56·4	58·7	81·2
7	47·4	40·6	81·2

It will be seen, therefore, that this objective presents considerable advantages. Let us see its disadvantages, which are common (and will, except the first, be always so) to all non-aplanatic objectives.

First, the necessity of correcting the focussing every time, seeing that the objective has a chemical focus.

Secondly, the forced employment of exceedingly small diaphragms, the aperture of which will be between $\frac{f}{40}$ and $\frac{f}{72}$. With the largest, $\frac{f}{40}$, the field is much less flat, and the image much less sharp, than with the smallest, $\frac{f}{72}$. Nevertheless, in this respect the periscope is superior to the globe-lens, its spherical aberration being much less considerable.

But the forced employment of such small diaphragms gives rise to photographic images which are flat, and without that vigour which only the employment of large diaphragms can secure. But, on this question, the reader can refer to what we have said at p. 92, bearing on the same subject.

The periscope is not so free from astigmation as the globe-lens, particularly if the most oblique pencils are taken into consideration. Still, however, this aberration is scarcely *perceptible.*

This objective possesses, therefore, much the same qualities as the globe-lens. But it will never côme into general use, because it requires diaphragms too small. With respect to other qualities of these lenses, we refer to the Preface to this book, in which we give our reasons against the employment of non-aplanatic objectives.

The Doublet of Mr. Thomas Ross.—This objective, of which the subjoined figure* is a section (representing exactly, and of the actual size, the one of 110 millimètres focal length), is composed of two achromatised meniscuses, N M and H G, (the surface G facing the object to be reproduced). Each of these meniscuses can be employed separately as a single objective. The two lenses are fixed in rings which screw into a tube, B B′, E E′, terminated towards the object to be reproduced by a larger tube, F F, on which the shutter fits. The tube screws on the flange A A′ fixed to the camera. The diaphragms, of which the maximum aperture is $\frac{f}{15}$, and the minimum one $\frac{f}{45}$, are graduated and constructed like those of the globe-lens. Further, a sliding-plate, Z, allows of the lens being opened or closed independently of the shutter.

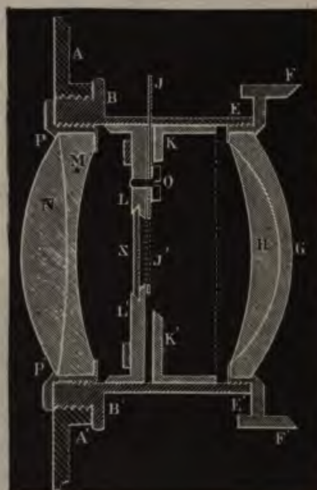


Fig. 68.

This objective is superior to the globe-lens, in that it possesses less spherical aberration, thus allowing of the employ-

* By a mistake of the draughtsman, the position of the two lenses in the woodcut is reversed. Let the subsequent description be read with this correction in view.—*Trans.*

ment of larger diaphragms. It includes an angle of 80°, and is nearly free from distortion. But it possesses the disadvantages common to the *globe-lens* and to the *periscope*, namely, the forced employment of too small diaphragms—disadvantages which we have dwelt upon in the Preface to this work, and also at p. 91.

Its use, like that of the globe-lens and of the periscope, is very valuable for the reproduction of inanimate nature, and particularly of buildings, at a very short distance. It gives images of a remarkable sharpness, and possesses a very great depth of focus, qualities which make it rank with the best non-aplanatic objectives.*

Section II.—*Aplanatic Objectives.*

The Orthoscopic Lens.—This objective has been invented by M. Petzval, of Vienna, and it is based on extremely ingenious calculations. The subjoined figure shows it as now constructed by Messrs. Harrison and Schnitzer of New York.

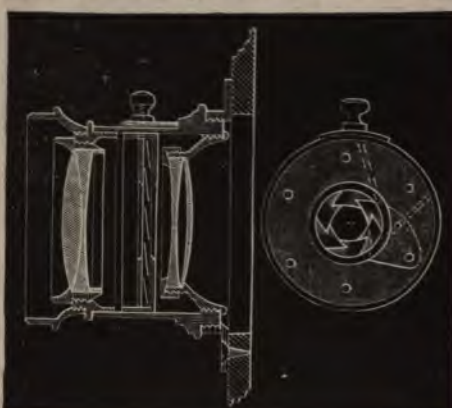


Fig. 69.

It is formed of an achromatic meniscus lens, of which the convex surface is towards the object to be repro-

* Several years ago, the late Mr. Goddard, of Isleworth, introduced to the notice of the public a doublet lens for architectural and copying purposes; it differed, however, in form from Mr. Ross's, and did not embrace *so large an* angle of view.—*Trans.*

duced. This meniscus is not entirely free from spherical, but is completely so from chromatic, aberration. Employed alone, in the position represented by the figure, it would give an image not very sharp at the centre of the focal plane, and in every case very deficient in definition at the margins. But behind this lens, and at a certain distance, is a second but divergent meniscus; the purpose of which is, firstly, to correct the spherical aberration of the entire system; and, secondly, to extend the focal length of pencils oblique to the axis, in order that the field may be rendered flat, as has been explained at p. 95.

The second meniscus is formed of two simple lenses, the combination of which is achromatic. The one lens, that towards the anterior meniscus, is bi-concave and of flint-glass; the other is a convergent meniscus of crown-glass. The two lenses cannot, therefore, be cemented together, like those which form the anterior meniscus.

The aperture of the orthoscopic lens is about $\frac{f}{8}$. It can be employed with its entire aperture, and acts then with very great rapidity, but the extent of sharp image is in this case not more than half its focal length. Between the two lenses is a diaphragm formed of imbricated plates of brass which permit of its aperture being diminished to $\frac{f}{30}$. With this aperture the sharp image becomes of a much greater extent, and equal to the focal length of the objective employed. With this aperture of diaphragm ($\frac{f}{30}$), the depth of focus of the objective is very considerable indeed, and the image is also very brilliant, since this diaphragm is, relatively to those employed with the globe-lens and the other non-aplanatic objectives, also very large.

In a word, the orthoscopic lens possesses all the advantages of the triplet, of which we shall speak presently, except that of absence of distortion. In fact, the orthoscopic lens reproduces fig. 55 as fig. 57. It is not, therefore, adapted for the

reproduction of buildings, engravings, &c. This is to be regretted, for it possesses some essentially good qualities.

The double Portrait-Lens.—This objective has been invented by Herr Petzval of Vienna, and described by this illustrious *savant* in a memoir presented to the Academy of Sciences of Vienna—a memoir which is a masterpiece in a mathematical point of view, but of which unfortunately we are unable to give the analysis here, because of the limited space at our disposal, and particularly because of the class of readers to whom this work is addressed.

Many opticians have claimed priority of invention of the double objective, on the grounds that they had constructed them with two lenses long before the publication of Herr Petzval's memoir. But these objectives were not at all in conformity with the compound lens universally adopted at present, were far inferior to it, and admitted of only an aperture of $\frac{f}{10}$. They were much like fig. 46, but the meniscus in front was smaller. These claims have no scientific value, and have besides, on this account, fallen at the present day into oblivion.

Fig. 70 represents, of the actual size, the double objective of Petzval constructed by M. Dallmeyer, bearing the name of the rapid lens for stereoscopic proofs, and having a focal length of 4.62 inches. This form unites the greatest perfection with the largest possible aperture $(=\frac{f}{4})$. The following are its numerical data, the nature of the glass being the same as that of the single objective described at p. 121.*

* The following are the indices of refraction of the kinds of optical glass made by Chance, of Birmingham, which English opticians employ :—

	Density.	Index of refraction.	Dispersive power.
Crown-glass, No. 1	2·48	1·50	0·039
Crown-glass, No. 2	2·51	1·52	0·04
Light flint-glass, No. 1	3·2	1·57	0·0473
Heavy flint-glass, No. 2	3·64	1·64	0·055
Very heavy flint-glass, No. 3 ..	3·84	1·64	0·059

This objective is composed, therefore—

1st. Of an achromatised meniscus, H G (nearly plano-

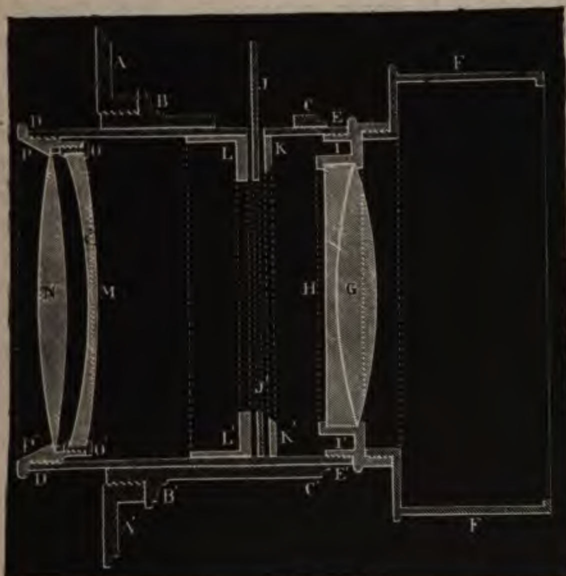


Fig. 70.

Diameter of the anterior combination		2977
Bi-convex crown-glass lens	$-R$	5585
	$-R'$	3701
Bi-concave flint-glass lens	$-R''$	3701
	$-R'''$	102662
Diameter of the posterior combination		3517
Divergent flint-glass meniscus	$-R$	13030
	$-R'$	5844
Bi-concave crown-glass lens	R''	10195
	R'''	10195
Distance between the two combinations		2424
Absolute focal length		10000
Total aperture of the lens	$\frac{f}{4} =$	2500
Aperture of the smallest diaphragm	$\frac{f}{25} =$	400

convex), the convex surface of which is towards the object to be reproduced; this meniscus, set in a ring, I I', screws on a

tube, D E E′ D′, which receives the larger tube, F F′, which is closed by means of a brass or pasteboard cap.

2ndly. Of a bi-convex combination, N M, formed of a divergent meniscus, M, of flint-glass, placed at a certain distance from a bi-convex lens, N, of crown-glass. The flint-glass, set in a ring, O O′, screws into the ring P P′, which receives the crown-glass. A ring separates the two lenses to the distance assigned by calculation. This lens is fixed to the other extremity of the tube, D E E′ D′. For other parts, the figure, drawn with great exactitude, makes the details of the construction quite clear.

L L′, K K′, are two discs between which the diaphragms pass. The aperture of the latter is so graduated, that, knowing the time of exposure required by one of them, that required by another is found by a simple multiplication.

Let us try to give an idea of the theory of Petzval's lens. For this purpose, let us remove from the lens the posterior combination (that which is towards the ground glass). The combination in front, the form of which is slightly plano-convex, is very nearly free from spherical and chromatic aberrations. The image that this lens will give of *objects situated in its axis, or very slightly oblique to it*, will therefore be very sharp, but of very small extent in relation to the focal length. On the other hand, it will be very brilliant. But for objects situated out of the principal axis, the image will be very confused, the field being much curved.*

* Turned the other way, and furnished with a diaphragm, the lens gives an image less brilliant, but sharp, over a greater extent of the ground-glass. In fact, we have then the single, primitive objective, described at page 115. It is for this reason that many opticians recommend their objectives as serving for both portraits and views, by replacing the lens N M (fig. 70) by the lens H G. This can be done by unscrewing the ring PP′, and replacing it by the ring E E′: the lens H G then presents its plane or concave face to the object to be reproduced.

But, as we have seen in the article on the *single objective*, this system can never be good, inasmuch as the front lens of the compound objective of Petzval has not the form which a good single objective ought to have.

The posterior combination (N M, fig. 70) ought therefore to unite the following conditions:—

1st. That of correcting the spherical aberration (positive or negative) which the anterior combination may possess, and of being itself free from this as well as from chromatic aberration.

2ndly. That of extending the focal length of bundles oblique to the axis, emergent from the front lens, while reducing astigmation to the least possible degree.

The front lens, H G, being selected arbitrarily, but as completely free from spherical and chromatic aberration as possible, the posterior combination, N M, is constructed from the formulæ of Professor Petzval. If the compound system be not free from chemical focus, another face is substituted for the plane face of the front combination, as we have explained, when describing the single objective, in the note at page 116, and the two lenses, N and M, are removed from or approached to each other in such a way as to correct the spherical aberration resulting from the preceding operation (that of correcting the chemical focus). If this be not done, the entire system may possess spherical aberration; and in this case it does not give images of that decided sharpness which a good objective ought to give.

In all cases, the data relative to the lens must be first very closely obtained by calculation, since the preceding corrections are not practicable beyond narrow limits.

The second condition is infinitely more difficult to realise. It is the negative lens of the posterior combination which, by its meniscus form, the convexity of which is directed towards the anterior combination, renders the field of the combination entirely flat. But to demonstrate this would need several pages of calculations, which, moreover, are to be found in Petzval's memoir.

Generally the anterior lens (that which is towards the object to be reproduced) is a little smaller than the posterior lens, or, if made equal to it, is reduced to a portion of its sur-

face by an opaque ring. The consequence of this is an equality of the luminous intensity of the image on a focal plane of a certain extent. For, let A and B (fig. 6, pl. I.) be the lenses of the double objective, the principal axis of which, H G, makes, with the oblique axis, I J, of a bundle, R R′, of incident rays, a small angle, G B I = a, such that the refracted ray, b e, meets the upper part, e, of the lens A. It is clear that, if the angle a increases, the image, the luminous intensity of which was equal over the focal plane, I J, will be so no longer, since the ray b e, emerging from the front lens B, will no longer traverse the second lens, A, and will strike the mounting, C D. To obtain a great equality of light over a focal plane of 30° in extent (the angle a being consequently 15°), it would be necessary either to increase the diameter of the lens A, or to interpose at M M′ a diaphragm which limits the extent of the bundle of oblique incident rays.

The latter method is preferable to the former, because there is great inconvenience in increasing the diameter of the lens A, an inconvenience which consists principally in the great value then assumed by the spherical aberration for rays oblique to the axis and by the astigmation, rendered evident in the image by the thickening of the lines (whether horizontal or vertical, according to the position of the ground-glass) of the object to be reproduced.

The field of the double objective is, with its entire aperture, generally much curved. It could easily be made flat by increasing the diameter of the posterior lens A, but for the inconvenience which we have just noticed. It is better to make the field flat (that is, render the image sharp at its margins at the same time that it is so at the centre) by employing a diaphragm, and seeking rapidity in the chemical processes on the photographic surfaces.

The double objective is intended for portraits, because it is the most rapid of all the optical combinations hitherto invented. Furnished with a very large diaphragm ($\frac{f}{5}$ or $\frac{f}{6}$), it only

covers sharply a small part of the focal plane ($\frac{f}{3}$), but with a smaller diaphragm, $\frac{f}{10}$ for instance, the extent of sharp image is greatly enlarged, and becomes from $\frac{f}{2}$ to $\frac{2f}{3}$. Lastly, with a diaphragm of $\frac{f}{20}$ the extent of the image becomes equal to f.

The depth of focus of the compound objective is very slight, particularly when used with all its aperture, so that this quality is only obtained on the condition of using objectives of very short focus, furnished with small diaphragms, which limit the aperture to from $\frac{f}{6}$ to $\frac{f}{10}$ for portraits, from $\frac{f}{10}$ to $\frac{f}{20}$ for groups, and from $\frac{f}{20}$ to $\frac{f}{30}$ for landscapes and buildings.

The double objective is very nearly free from distortion, on the condition that the diaphragm which it carries is placed between the two lenses, as we have represented at fig. 70; but at one time the diaphragm used to be placed (and is still by some opticians behind the time) at the front of the objective. Then distortion of the image occurs as with the single lens.

The Triplet.—We have already spoken several times of this remarkable objective, and, among others, at pp. 95, 101, &c.

The triplet which we shall here describe is constructed by M. Dallmeyer, who must be regarded as the inventor of this objective.* Fig. 71 represents *very exactly* the size, having 7 inches focal length. The following are the numerical data of the system, the glass employed being that of Chance, of Birmingham, identical as to index of refraction and dispersive power with that of the single objective described at p. 120. (See also the note at p. 137).

On inspecting the figure, the construction of the triplet will be at once comprehended, of which, however, the following is the description:—

* *See foot-note, p. 101.*

G H, I Q, J K, are meniscuses, achromatised, and forming single lenses, though each is composed of two cemented toge-

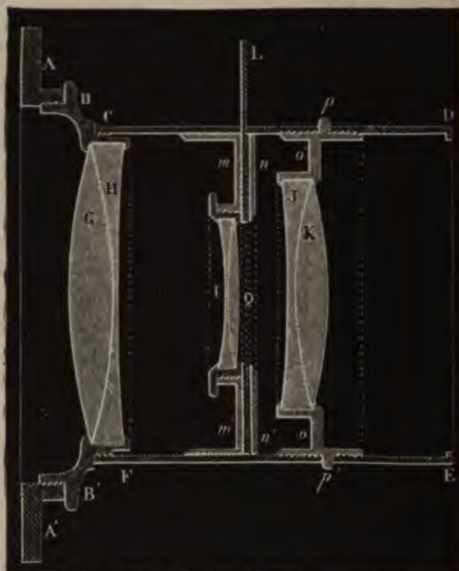


Fig. 71.

Diameter of the front lens J K		1714
Bi-convex crown-glass lens	+ R	3128
	+ R	2386
Bi-concave flint-glass lens	— R	2386
	— R	20223
Diameter of the negative combination I Q		1071
Bi-convex flint-glass lens	— R	14200
	+ R	4528
Bi-concave crown-glass lens	— R	4528
	— R	3200
Diameter of the combination H G		2286
Bi-concave flint-glass lens	— R.	30300
	— R.	3557
Bi-concave crown-glass lens	+ R.	3557
	+ R.	4728
Distance between the lenses H G, J H		1257
Focal length of the system		10000
Aperture of the largest diaphragm	$\frac{f}{10} =$	1000
" " smallest "	$\frac{f}{30} =$	333

r at their common surface. The first and last are conver-ıt, and the middle one is divergent. The three are mounted a tube, C F E D, D E being capable of being covered with asteboard cap. This tube screws on a flange, A A′, which ixed to the camera.

The diaphragms L are graduated, and introduced between) discs, *m m′*, *n n′*.

When it is desired to make use of this instrument for land-pes or for reproductions of a natural size, the combination (the smallest) ought always to be turned towards the ect to be reproduced, and the combination G H (the largest) ards the ground-glass of the camera; but when it is shed to use it for enlarging, the combination ought to be ersed and turned the other way, G H being towards the ect to be reproduced, and J K towards the screen or the sitive surface placed in the camera.

For groups and for instantaneous effects, the objective ght to be employed with the largest possible aperture, as to obtain the maximum of rapidity. But for land-pes and for reproductions, when the time of exposure is of s importance, smaller diaphragms may be employed (this one of the reasons why the triplet will be generally pre-red to the globe-lens), by recollecting always that what is led depth of focus can never be obtained legitimately except using small diaphragms.

If it is desired, the combination I Q can be removed by st screwing off the combination G H. When the combina-ns G H and I K are alone employed, the focus is found to reduced to a half, and the rapidity of photogenic action is ınd to be consequently increased to the same extent; but ough in this case the system may be achromatic, the field oduced is much too curved, and the apparatus cannot serve an instrument for portraits, unless in some special cases. rticularly when it is required for portraits taken out of ors, for groups or reproductions, the three combinations ıst be employed, arranged as indicated in the figure.

The advantages and disadvantages of M. Dallmeyer's triplet are as follow:—

1st. With equality of focal length, it covers sharply a focal plane much larger than does the ordinary single objective, but not so large as the new single objective of the same optician, and particularly Mr. Ross's doublet and M. Steinheil's periscope.

2ndly. It is, within practical limits, free from distortion, but not from astigmation, like the globe-lens.

3rdly. But it is free, along its axis, from spherical aberration, which is very valuable in the production of animated scenes, portraits, and groups in the open air, &c. In this respect it is superior to the orthoscopic lens, and especially to the ordinary double objective, the depth of focus of which with the same aperture is much less than that of the triplet.

4thly. With a diaphragm the thirtieth of the focal length, it covers sharply an extent of focal plane of which the greater side equals its focal length, and this aperture of the diaphragm is sufficient for giving brilliant images. If from insufficiency of light, or from any other cause, the diameter of the diaphragm has to be increased, the sharpness of the image does not diminish (the extent of surface sharply covered only diminishes). This advantage is in practice so considerable, that it makes the triplet the most indispensable of all known objectives. The use of the triplet is therefore nearly universal.

CHAPTER VII.

THE EMPLOYMENT OF PHOTOGRAPHIC OBJECTIVES.

In this chapter we purpose to describe the mode of using objectives in the different branches of photography—namely, for *portraiture*, reproducing *landscapes*, *buildings*, *maps*, *pictures*, *photographs*, &c.—and the precepts common to all these processes—namely, *the focussing*, the *time of exposure*, varying with the aperture of the diaphragm, the previous trial of *the position of the ground-glass* of the camera, and the *testing* of the objective as regards the *chemical focus* which it may possess. We shall in this description follow the natural order of the operations.

The Camera.—The camera employed by photographers is so well known that any description of it is needless. The following are the principal points to which we call the attention of the reader:—

1st. A glass finely ground, which may even be rubbed with a little oil so as to render the grain finer, is necessary for exact focussing.

2ndly. It is necessary, before using a camera, to verify if the ground-glass and the glass-plate in the slide occupy exactly the same place, and, in order to do this, to measure with a rule their distance from the brass ring of the objective fixed on the front of the camera.

3rdly. The objective ought to be fixed to a small board, sliding in two vertical grooves on the front of the camera. This is indispensable for the reproduction of views and buildings.

4thly.—In no case ought the plane of the ground-glass to be

capable of being inclined to the axis of the lens, as it is made to be in some portrait-cameras.*

The Focussing.—To focus is to render the image on the ground-glass as sharp as possible. When the objective has a small aperture and a very great focal length this is very easy; but when the objective has a short focal length and a large aperture, it is infinitely more difficult, because then the least derangement of the ground-glass changes the sharpness of the image, for the reason we have explained at p. 85.

For rigorous focussing it is well to make use of the magnifier, represented by fig. 72. It is formed of two plano-convex lenses, *a* and *b*, the convexities of which are towards each other, fixed at the extremities of the tube C, sliding with gentle friction in the tube B, screwing into a larger tube A, which is applied, during the focussing, at the part where it may be deemed to be necessary. We first adapt the magnifier to our sight by sliding the tube C in the tube A, taking care that no one disarranges the magnifier afterwards; for every one must regulate it to his own vision, else a very great error might be caused in the focussing, particularly if the ground-glass is fine and oiled.

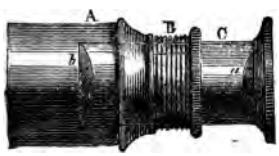


Fig. 72.

When the camera is directed with its objective towards the object to be reproduced, select in the latter a sharply defined point placed at the centre of the ground-glass, and another placed at its edge, both as nearly as possible in the mean plane, that is to say, chosen between the fore and back-grounds. (In examining the ground-glass, the head is covered by a black cloth, which envelopes the upper part of the body, and also the camera, except its objective).

* In our *Traité Général de Photographie* we have stated the contrary, but a more attentive examination of this question has proved to us our error.

On advancing or withdrawing the ground-glass and examining with the magnifier the image of the point at the centre, we easily succeed in giving it all the sharpness possible. Passing, then, to the point at the edge of the ground-glass, we see whether the image is sharply defined. Ordinarily it is not so, but the intermediate points become more defined the nearer they are to the centre. The ground-glass is always, after the focussing, fixed by a pressure-screw.

When the objective is *aplanatic* (see p. 75), the image can be focussed with a large diaphragm. The image is then better observed, but we must, in this case, choose for focussing a well-defined object somewhere between the fore and back grounds and situated at the centre of the ground-glass. For the large diaphragm there is then substituted a smaller one, which extends the sharpness to a surface of the ground-glass so much the greater as the diaphragm is smaller. But with *non-aplanatic* objectives it is necessary for exact focussing to make use of one of the smallest diaphragms.

This is easily conceived, if it be recollected that any point chosen in the object to be reproduced forms the summit of the luminous bundle of which the lens is the base, and the focal plane the point where the rays meet. The diameter of the aperture of the objective has no influence on this point if the objective is *aplanatic*, so that, with or without diaphragms, the objective must reproduce the object with the same degree of sharpness. The employment of the diaphragm only causes the sharpness of the image to be distributed over a greater surface by increasing the depth of focus.

Properly speaking, when the objective is furnished with a very small diaphragm, the position of the ground-glass for the sharpest possible image is not fixed (see p. 85); hence the difficulty of focussing with this kind of objectives, a difficulty which is not experienced with an aplanatic lens previously furnished with a large diaphragm, which gives at once more

clearness to the image, and limits the sharpness to determined points. This sharpness is extended on the substitution of a small diaphragm for the large one.

Calculation of the time of exposure.—The time of exposure has the greatest influence on the artistic value of a photographic proof. Too much exposure gives dull proofs, too little exposure harsh proofs, and a proper exposure brilliant images with shaded skies, deep shadows, etc.

According to M. Léon Vidal, of Marseilles,—who has published a small work on this subject, entitled *Calcul des temps de pose*, which is remarkable for precision, and from which this account is only an extract,—the following causes make the time of exposure vary:—

1st, the intensity of light at the moment of the operation; 2nd, the sensibility of the surface submitted to the impression; 3rd, the greater or less reflecting power of the object to be reproduced; 4th, the ratio of the diameter of the diaphragm to the focal length of the objective employed.

M. Vidal measures the intensity of the light by exposing for one *minute* a piece of ordinary albumenized paper to daylight (in the shade), and afterwards compares it with a series of ten printed shades, selecting that one the coloration of which approaches the nearest to the tone of the paper, the *number* of which furnishes one of the elements of the calculation of the time of exposure.

The sensibility of the surfaces submitted to the impression is as thus determined, in the following ratio: *dry collodion with tannin*, 3; *moist collodion*, 24; *albumen*, 1; whence it follows that wet collodion is eight times as rapid as dry collodion with tannin.

The reflecting power of bodies becomes appreciated by habit; but attention need only be paid to it in exceptional cases, such as the reproduction of landscapes, where green would be predominant, that of pictures, where red, yellow, and green would prevail, etc.

Lastly, the fourth datum is the most important. M. Vidal

at once admits that within a small fraction nearly all objectives are equally rapid if the ratio between the aperture of the diaphragm and the focal length be the same. All objectives, therefore, of which the diaphragm is $\frac{f}{30}$ give the same intensity of image, whatever f (the focal length) may be, which is in fact the case.

But M. Vidal expresses the f in a series of figures which he takes from 10 to 90 centimètres, along with diaphragms of variable apertures; so that, in this way, his tables attain a length which they would not have reached by taking the ratio between the aperture of the diaphragm and f. But on this account his tables are more practical; for, in our system (and this is an improvement which every optician should carry out) the constructor of the objective ought to adopt, as indeed he does, focal lengths determined by the dimension of the focal plane, and then apertures of the diaphragms which are exact fractional numbers of this distance, such as $\frac{f}{40}$, $\frac{f}{30}$, $\frac{f}{20}$, $\frac{f}{10}$, $\frac{f}{8}$. In this way, all imaginable objectives could be compared together just as the variable diaphragms of the same objective.

However this may be, M. Vidal introduces in his tables the preceding elements, which, in the main, are, for the operator, confined to the measurement of the intensity of the light, a knowledge of his lens, and the consultation of the tables; and he thus obtains exactly the time of exposure.

Let us add, further, that if there are some slight causes of error in the calculation of the time of exposure, this may vary within certain limits without very sensibly changing the results. But many who practise photography have only a vague appreciation of such matters; and, therefore, real thanks are due to M. Vidal for his remarkable and useful work.

Trial of the chemical focus of the Objective.—It is of the highest *importance*, before adopting an objective, to try if

it has not some chemical focus, and this is how we proceed to test it:—

Place at some mètres from the objective to be tested the *focimeter*, the image of which must be formed at the centre of the ground-glass. This focimeter is formed (fig. 73) of eight segments of pasteboard, numbered and placed at equal distances from each other along a cylinder of wood in such a way that their assemblage seen from their face forms a circle. Bring rigorously to a focus the card No. 5, and, in order to avoid all error, use a ground-glass placed in the dark frame which will afterwards receive the sensitised plate.

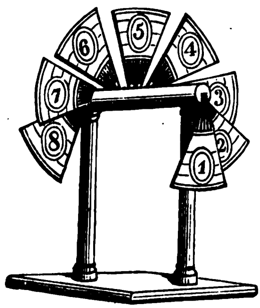


Fig. 73.

This being done, substitute the sensitised plate for the ground-glass, take a proof, and see if the card No. 5 be rigorously sharp. If not, your objective possesses a chemical focus. If the card No. 6, 7, or 8 be the sharpest (instead of No. 5 focussed by the eye), the chemical focus is longer than the visual focus, and after every focussing it would be necessary to draw out your camera to an extent variable with the distance of the object to be reproduced. If it be the card No. 1, 2, 3, or 4, the reverse must be done.

The employment of the Objective for taking portraits.—The only objectives which should be employed for portraits are: the *double lens* in the studio; the *triplet* and the *orthoscopic* in the open air. What follows relative to their employment applies to all three, but more particularly to the first, the use of which is the most general.

Firstly, there must be procured a wooden stand, *very massive*, in order to avoid vibrations (iron stands are in general to be rejected for this purpose), and which can be *lowered or raised* so as to bring the lens to the height of the loins of

a person sitting, and to that of the chest of a person standing up. The axis of the objective ought to be capable of inclining downwards to a small extent, but to abuse this allowance is to run the risk of obtaining deformed proofs, for theoretically the axis of the objective ought always to be maintained rigorously horizontal.

To prove this let B C D E (fig. 7, pl. I.) be a person seated, and A the objective placed too high, and consequently requiring to be inclined at a downward angle. It is clear that the angle *a* subtended by the horizontal part, C D, of the legs will be much greater than if the objective were placed at A', at the level of the loins, in which case the angle *a* is much smaller, and in accordance with truth; for in the photographic reproduction, the person will appear to be seated on a chair the seat of which is inclined, in the case where the objective has the position A.

If the person is standing (fig. 8, pl. I.), the objective ought to have its axis *horizontal* and on a level, D C', with his shoulders, *a*. It will be necessary *to lower* the stand which carries the objective D, so that the image, *b a c*, of the person may fall on about the middle of the ground-glass, in order to give the space, *b c*, above the head nearly equal to the space, *c*, beneath the feet. By proceeding in this way the image cannot be at all deformed.

Few photographers operate in this way, but incline the axis of their objective so that the image is thereby deformed. To keep the axis of the objective on a level with the loins in reproducing a person in the standing position is contrary to the laws of perspective, he always having then, in the photograph, his neck too short. It is better, then, to do as we have stated above. We may add that if the objective has a long focus, a slight inclination of its axis produces, as in the case of views, a very evident deformation of the image.

Reproduction of Landscapes.—For this kind of photography, the *single* objective, which we have already described, the *triplet*, and the *orthoscopic*, answer the best, because it is

often requisite to employ large diaphragms on account of the little photographic power of green, the prevailing colour in landscapes.

As landscapes do not present straight lines, the operator may incline the axis of his apparatus upwards or downwards without causing perceptible deformation in the image. This is all that it is necessary to say here concerning this kind of photographic reproduction.

Architectural reproductions.—If the building be very near, and if persons are not required to be seen in the proof, the *doublets* of Mr. Ross (p. 133) and of M. Steinheil (p. 130), and the *globe-lens* (p. 124), are the most suitable for the purpose. If the building be not so near, and particularly if persons are desired in the proof, then the *triplet* (p. 141) is to be preferred, seeing that it allows of the employment of larger diaphragms, and consequently of a shorter exposure to the light. The *single* objective and the *orthoscopic* do not answer at all, on account of the distortion (p. 96) which they produce in the image.

The essential point in the reproduction of a building, C B A (fig. 9, pl. I.), is to keep the camera, D E, perfectly horizontal. Most usually in this case the image of the summit, A, of the building falls outside the ground-glass of the camera; but to obviate this inconvenience, the wooden slide carrying the objective, H, must be elevated until the image, *c b a*, of the building occupies the desired place on the ground-glass.

If, instead of proceeding in this way, the objective were pointed upwards, the vertical lines of the building would then incline towards each other, as shown in fig. 10, pl. I. Such a course of procedure must be avoided.

If in the reproduction of a building we are in a high position, the slide carrying the objective must be lowered, and not the axis of the objective declined; else the same want of parallelism of the vertical straight lines is produced, but in the opposite direction to that in the case just now considered.

It is true that, by proceeding in the way described, part of

the building is always deficient in sharpness (the summit A, for instance, as shown in fig. 9, pl. 1), and it is so for the reason, that, by raising the objective H, so that its axis, B *b*, is higher than that of the axis, *o o'*, of the camera, we make it serve for a dimension of the focal plane greater than that for which it was constructed. For *b o* increases in the ratio of B A; whence it follows that the more lofty the building, the less sharp will its summit, A, be. But better sacrifice the sharpness of this part of the image than obtain those unfortunate distortions in which the houses are seen falling towards the street, towers leaning, &c., and which cause the photographic art and the objectives to be unjustly accused of deforming the images—a reproach only merited by the operator ignorant of the precepts of optics.

As regards the want of sharpness in the summit of a building, it can in many cases be partly avoided by placing ourselves with the apparatus as far off as possible, and entirely avoided by placing the apparatus at a height equal to half the total height of the building.

Reproduction of Engravings, Drawings, Maps, Pictures, Photographic Proofs, &c.—For this purpose, the same objectives are employed as those for taking buildings. To keep the camera horizontal, the face of the engraving exactly vertical, the point of intersection of the diagonals drawn between the opposite angles of the map, picture, &c., exactly in the axis of the objective, which is seen by the image then covering the ground-glass symmetrically—these are all the optical instructions for this kind of photography.

The objective is to be *reversed* if an enlarged reproduction has to be obtained, that is, the lens which ordinarily faces the ground-glass is in this case to be towards the object to be reproduced. For this purpose, the triplet and the orthoscopic are to be employed in preference, because of their large aperture, which allows of a short exposure as compared with that of the non-*aplanatic* objectives mentioned at p. 75.

In reproducing a drawing or a photograph of the same size as or larger than the original, it is advisable to use an objective of longer focus than is theoretically necessary, because when the distance between the object and the objective is too short there is great difficulty in illuminating the object properly. Thus, *triplets* and *orthoscopics* of 10 or 12 inches focal length ought not to be employed for reproductions, identical in size with the object to be reproduced, of more than about 6 by 8 inches. It is otherwise when the reproduction is smaller than the object.

In the case of reproductions, particularly those of daguerreotypes and photographs on glass which reflect light, a large disc of black velvet with the same aperture as, and in close contact with, the objective, is interposed between them. This is to prevent the image of the object receiving that of the objective by reflection from the polished surface of the object to be reproduced.

BOOK II.

APPARATUS FOR ENLARGEMENTS.

The future of photography rests in the practical solution of the amplification of small photographic images. In fact, with the optical means actually at our disposal, we can produce with certainty a small proof—the size of a card picture, for example—of absolute sharpness, both at the centre and margins.

If we effect the enlargement of this proof with a perfect apparatus, we shall obtain from it a proof of plate size, double plate, entire sheet, and of even 1 mètre high, with an extreme perfection, such, that any objective, employed directly, cannot produce one either so beautiful or so fine. The author of this work has, in fact, proofs of the size of the photographic sheet (44 centimètres by 57) so sharp, that in the opinion of opticians of the highest merit, such as Messrs. Sécretan, Ross, and Dallmeyer, nothing can be produced so fine by the use of large objectives.

All the importance, therefore, of this part of our work will be pereeived. We shall divide it into chapters, wherein we shall separately examine :—

1. The production of the negative intended for enlargement.
2. The amplification of the negative (enlarging apparatus).

CHAPTER I.

ON THE NEGATIVE INTENDED FOR ENLARGEMENT.

In this chapter we have to examine:—

1st. The *optical apparatus* for producing the negative.

2nd. The *photographic process* to be followed for obtaining the negative.

SECTION I.—*The optical apparatus suitable for producing a very small perfect negative.*

Influence of the focal length of the Objective.—If a camera furnished with an objective be directed on a man who is walking away, his image on the ground-glass becomes smaller and smaller, while, on the other hand, it is necessary to bring the ground-glass constantly nearer to the objective, in order that his image may remain sharply defined. There is, however, this to be remarked, that if the man be very close to the objective, (which to fix our ideas we shall suppose to have a focal length of·30 centimètres) for example, 3 or 4 mètres from it, the movement to be communicated to the ground-glass is then very considerable, and that, in proportion as the man moves off, a point is soon reached when on the contrary this movement becomes absolutely nothing. Then the distance which separates the man from the objective is such that his image is formed at the principal focus of the objective.

Experience shows that if an object be situated at a distance of a hundred times the focal length of the lens, its image is then formed at the principal focus of the lens, the same as that of all objects *situated further away.* A perusal of pages 85, *et seq.*, will clearly demonstrate this fact. Therefore, in order

to produce a good negative, the object must be very distant. But how is this to be reconciled with the short length of glass studios, or, in the case of views, with the short distance which always separates us from the foregrounds? Evidently by making use of objectives of *very short focus*.* It is true, the image will be in this case very small, but it will be sharp at all points.

It is, in fact, necessary to be thoroughly impressed with the principle that an objective of very short focus has the property of giving equally sharp images of objects at different distances away, provided these are at a distance from the objective at least equal to 100 times its focal length. For portraits, therefore, the best objectives are the smallest. Let us now see the influence of the diameter of objectives on the sharpness of images and the truthfulness of perspective.

Influence of the diameter of the Objective.—An objective which has a very large diameter as compared with its focal length, produces images not only of very unequal sharpness at their centre and at their margins, but also faulty as to the perspective. The latter point will be understood when it is considered that every point of the objective has a different view of the object to be reproduced, and that the image of this object is made up of an infinity of different superposed images, one of them being formed by every point of the surface of the objective. Therefore objectives of large diameter always deform the reproduced object. It is precisely for this reason that all objectives which have more than two inches aperture do not give by any means such sharp images as would be obtained by enlarging a very small negative. An objective of three inches, much more one of four, five, or six inches, never gives images *sharp* over all the surface of its focal plane. On the contrary, an objective of one inch, or even of *two* inches, gives an image *sharp* and truthful (without de-

* We do not mean by *objectives of very short focus* objectives with very large diameter relatively to their focal length, as is usually meant, but very small *ordinary objectives*.

formity), because in this case the diameter is too small in relation to the distance which separates the objective from the object to be reproduced. Many photographers, therefore, are already giving up objectives of five and six inches, and the number of those doing so will increase much more as the use of the apparatus for enlarging becomes more extended.

If the dimension be made less than this, as the enlargement required for a given size of paper is more considerable, the least defects of the glass or of the collodion film become very apparent.

Apparatus suitable for Portrait-Negatives.—The apparatus most suitable for these are the *carte-de-visite* objectives, by proceeding in the way we have indicated at page 150.

Apparatus suitable for Landscape-Negatives.—The best size for a negative for enlarging, in the case of views as well as of portraits, being that of the *carte-de-visite*, small objectives are preferable to large ones.

Messrs. Ross and Dallmeyer, the celebrated English opticians, construct small triplets, which have only three or four inches focal length, and which give proofs of *carte-de-visite* size of an absolute sharpness at the margins as well as at the centre. If the foregrounds are situated more than about twenty-five feet from the objective, and if this is never intended to be used but for negatives destined for enlargements, it should then be mounted on a small camera *without sliding movement*, and in which the ground-glass is fixed, as in the self-acting camera of M. Bertsch, which we describe below. We must never forget the recommendations laid down at pages 151, *et seq.*

Self-acting Camera of M. Bertsch.—M. Bertsch has constructed small cameras, specially intended for landscape-negatives, in which no focussing is necessary, in virtue of the principle already given (page 157). Fig. 74 is an exact drawing of it. Raised on its stand at the distance of ten feet, it takes in an angle of about 23°—an angle much smaller, how-

ever, than that which would be taken in by a triplet. The lens, G, which M. Bertsch uses, is a single objective of the old construction (p. 119).

A is a cubical box of brass, carrying the quadrangular appendages I and L, intended to render it rigid. C is a spirit-level, and B a sight which serves for placing the landscape in the best position on the frame M. As much of the landscape as is included in the frame B will be reproduced on the sensitised glass placed in the frame M. E is a spring-shutter with an elastic spring, which holds the glass closely against the corner pieces of the frame. The glasses used by M. Bertsch are eight centimètres square. He has also constructed, on the same principle, self-acting portrait-cameras, in which the single is replaced by the double combination.

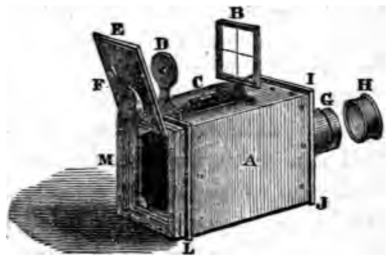


Fig. 74.

SECTION II.—*The Photographic Process.*

The Glass.—Thin glass should be selected, 2 millimètres thick at the most, and as uniform in thickness as possible, because the heat of the sun, condensed by the semi-transparency of the image, very quickly causes *plate-glass* to break in pieces, while *blown-glass* will stand this strong heat much better. Small bubbles and other defects of the glass (such as inequality of the surface) have no influence on the perfection of the enlarged image. The thickness of the glass has a great effect upon that accident to which the glass is liable, of breaking under the influence of the solar rays; the thicker it is, the less likely is it to stand their heat. In this respect

it is like plate-glass. There is, besides, another inconvenience in using thick glasses, which is, that they alter the path of the convergent rays which pass through them, and that in this case it is necessary, with unfailing attention, to keep the solar rays in a constant direction, or else the outlines of the image will be doubled, particularly at their margins. With thin glass this defect is not appreciable.

The Process.—The only process which is suitable for negatives intended for enlargements is the collodion process. What is necessary, in fact, for such a negative, is great transparency, of which one can scarcely have any correct idea until after having seen negatives made by experienced operators. The dry collodion and the albumen processes have not given such good results as the wet collodion process. Nevertheless, these ought to succeed when properly employed, as well as the wet collodion process.

This transparency of the negative, to which we cannot too much call the attention of the reader, and to which we shall again have occasion to call it, is necessary for several reasons. In the first place, in the apparatus for enlarging, the solar light ought freely to traverse the negative, else there will be extreme heating of the glass, and consequent fracture. Secondly, several images are found superposed on the paper, the optical apparatus acting, firstly, by the light *transmitted*, then by that emitted, by every point of the negative. Lastly, all the sharply-defined outlines of the negative are found doubled on the enlarged proof, phenomena of diffraction being produced, to which we shall by-and-by return.

Now, to obtain this extreme transparency of the negative, and, above all, a complete absence of fogging (which has the bad effect of requiring an exposure double and triple of that which would be necessary if it were not fogged), there must necessarily be a well-prepared collodion, silver bath, and developer.

All collodions, silver baths, and iron developers are good *if they* produce good results in the ordinary process. To give

formulæ here would be of no use. But the following is the mode of operating, which is of more importance:—

The glass covered with sensitised collodion is exposed in the camera a little longer than usual. It is easy to understand the object of this longer exposure. If a just sufficient exposure were given, the iron would only bring out the details in the shadows after some time, during which the blacks would have acquired too great an intensity; whereas, by giving a longer exposure, the image at once appears in the shadows as well as in the lights. The negative is then, after exposure in the camera, carried to the dark room, and the glass is removed from the frame. A considerable quantity of iron is taken in a lipped glass, and a trough full of water placed ready to hand. The iron is poured over the negative, covering it very abundantly so as to remove all the nitrate of silver which is on the film. In a word, to give thorough expression to our meaning, the negative is washed with the iron. The image appears, and the moment the details in the shadows come out, the glass is plunged into water, washed, and fixed with cyanide of potassium.

All the skill consists in operating very quickly. First, flood the negative with iron, and just before fogging has had time to appear (most usually five or six seconds after having applied the iron), at once arrest the action by a copious stream of water, and fix with cyanide (not with hyposulphite).

The dry negative examined by daylight ought barely to allow the details in the shadows to be seen: the blacks ought to be so feeble, that one could read through them, and even observe the most delicate objects; otherwise the enlargement will never be perfect. Above all, avoid fogging. It is often preferable to produce a negative too intense (provided it be not fogged) than one too faint. For there is a simple and easy method of lessening the intensity of negatives, which is also applicable to old negatives provided they have not been varnished. This is the method:—

The negative *is first* wetted with distilled water: if the

film has a tendency to separate, previously varnish its edges with a brush dipped in a solution of caoutchouc in benzole. Then dip the negative in a solution of one gramme of sublimed perchloride of iron in 100 grammes of distilled water, for a time varying from some seconds to several minutes. The chloride of iron attacks the image, but only at its most intense parts. Wash the negative in water, dip it in a weak solution of cyanide of potassium, and wash again with water. The intensity of the negative will be found to be diminished. If it be too much so, then it has been left too long in the chloride of iron; if it be too little, repeat (even several times) the same treatment.

No varnish, not even gum, can be applied to the negative; varnish and gum, on getting heated, would entirely spoil the image. This point is of extreme importance. Besides, the varnish partly destroys the fineness of the image; an assertion which appears paradoxical, but which most accurate experiments enable us to make.

For the rapid process with nitro-glucose (proofs by development), a good ordinary negative (but not fogged) gives excellent results; this process generally giving proofs in which the contrast of the blacks and the whites is less than with albumenised paper. Even varnished negatives—which have not been made expressly for enlargement, and which would require with ordinary albumenised paper a very considerable exposure to the sun's rays—can be used for enlargement by the development-process.

CHAPTER II.

HISTORY AND SUMMARY DESCRIPTION OF THE APPARATUS FOR ENLARGEMENTS.

THE object of apparatus for enlargement is to produce proofs of a large size from a very small negative—of *carte-de-visite* size, for example—with a *uniform sharpness* all over their surface, which cannot be obtained without its employment. The sun being the source of the most intense light we possess, it is usually by means of the rays of this body that we work; in this chapter we shall only treat of the apparatus used with this light.

Two methods naturally present themselves by which to throw an enlarged image of a negative on a surface sensitive to light and capable of retaining it. One is to illuminate the negative by the direct rays of the sun; the other, to illuminate it by these rays first concentrated by a lens. A lively discussion has taken place between several *savants* as to the superiority of one method over the other—a discussion which will engage our attention in the next chapter.

SECTION I.—*Woodward's Apparatus and its Modifications.*

This apparatus (fig. 75), often described under the name of the *American solar camera*, is composed essentially of a large lens, I (fig. 75), called the *condenser*, at the principal focus of which an achromatic objective, L, is fixed. A mirror, A B, throws the solar *rays*, *r r*, on the condenser, I; and the negative,

J, moveable by means of a rack, K, is placed between the two lenses at a distance which varies with that of the screen on which the image is to be formed.

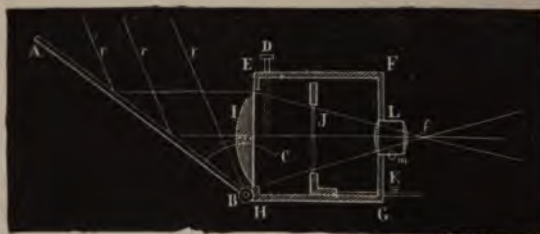


Fig. 75.

Such is the apparatus as a whole. Let us now pass to its details.

The condenser is 8 inches in diameter, but may be larger; if possible, 50 centimètres in diameter. The reason of this is very simple: the larger this lens is, the more light it collects, and the more quickly, consequently, is the positive printed.

Its focal length should not be less than twice its diameter, nor more than three times.

The objective, intended to be placed at L, should be corrected for its chemical focus. Its place is a little in advance of the focus, *f*, of the condenser. An ordinary objective, single or double, serves for this purpose, but the greatest care must be taken that the lens of the objective which faces the ground-glass, as ordinarily used, now faces the negative, J.

The negative should be moveable in the direction of the axis of the optical system; consequently, the apparatus should be specially constructed with this object. This is the use of the rack K.

The most usual form of the solar camera is that of a large square box, E F G H. The adjustible mirror, which we have described at page 12, is attached to the apparatus, at the extremities of which are the condenser, I, and the enlarging lens, L.

The management of the apparatus is very simple. It is sufficient to place the part E H B A of the solar camera in an opening in a darkened window; to communicate, by means of the adjusting screws B and D, the movements necessary for keeping the solar rays always reflected in the same direction, I *f*; to properly adjust the negative, J, so that its enlarged image is sharply formed on a screen, placed at a distance and perpendicular to the optical axis of the apparatus; and, lastly, to substitute for the screen a sheet of sensitive paper, or some other photographic surface.

Modifications introduced into the Solar Camera of Woodward.—Each time that the screws for moving the mirror were touched, the apparatus was shaken, and a corresponding movement imparted to the image, the more considerable according as the enlargement was greater. Besides, the wind, or the least agitation of air, is sufficient to shake the apparatus, and in this way destroy the sharpness of the image.

M. Wöthly, photographer, of Aix-la-Chapelle, introduced the first modification in Woodward's apparatus, by detaching the mirror from the apparatus. He formed it (fig. 7, pl. III.) of a large mirror, A, turning on pivots between two uprights, B and D. A weight attached to the upper part of the mirror tended to move it in one direction, but it was maintained in the other by a cord, *a*, which passed into the dark room, and over a pulley worked by an endless screw. Two cords, *b* and *c*, communicated to the mirror its second movement about its vertical axis, which was supported by the tripod C.

The situation of the mirror was towards the north, the silvered part of the mirror, A, looking towards the south over the roof of a small building slightly elevated. The reflecting instrument was therefore placed some mètres away from the apparatus (and in the open air), as we explained, page 15. The solar camera, properly so called, was composed of a condenser, A (fig. 6, pl. III.), to which M. Wöthly gave 10, 14, 18, 24, 30, and even 36 inches diameter, and the plano-convex form. This lens had a focal length equal to about one and

a half times its diameter. It was mounted in an iron ring made fast to three iron rods, B, C, D, equi-distant from each other, and perpendicular to the plane of the lens. On these iron-rods was fixed, in a permanent manner, the objective F, at the focus of the condenser. The holder of the negative, E, is moved between the objective and the condenser, by means of an endless screw, not represented in the figure. The apparatus was entirely of iron, and was enclosed in a wooden box.

M. Hermagis, a French optician, who has made himself famous by the large number of excellent objectives which he has sent out, also introduced a modification of the primitive apparatus of Woodward. His adjustible mirror was detached from the apparatus, and was very nearly the same as that we ourselves use in our dyalitic apparatus. But the mirror, instead of being suspended about its centre of gravity, which is necessary to produce stability, was suspended at its lower part by an arc attached to the side of the mirror. The whole weight of the mirror, therefore, rested on a point, so that its flexion was considerable, and had the inevitable consequence of altering the parallelism of reflected solar rays. This was a great defect.

At a certain distance from the adjustible mirror the solar camera was placed. This was identical with that of Woodward, except that the frame for the negative received in his arrangement two movements by means of adjusting screws, the object of which was to fix the central part of the negative in the axis of the optical apparatus. Moreover, M. Hermagis introduced between the negative to be enlarged and the condenser a moveable ground-glass. It was thus possible to work with either diffused light or the direct rays of the sun, according as the ground-glass was interposed or withdrawn. Lastly, the solar camera was connected with the adjustible mirror by a cloth cylinder, in order to shut out the daylight which might enter obliquely through the interval between them.

Solar Cameras without a Reflector.—Since the origin of enlarging processes, several persons, under the false impression that the mirror caused much of the light to be lost (in

reality, not an eighth of it is lost), directed their apparatus towards the sun, mounting all the parts on a single piece of wood or iron.

The first apparatus of this kind was described in England in 1863 by Mr. Stuart, the arrangement adopted by him being the following:—

The condenser, fixed in a very long box, is followed by the negative and the objective, precisely as in the American apparatus. On the box is fixed a cone, at the bottom of which is the frame on which the sensitive paper is stretched. Mr. Stuart places two of these apparatuses side by side, protects them from the wind, and makes them move with the sun by means of two movements, one horizontal, the other vertical.

Solar Camera of M. Liébert.—M. Liébert, of France, has produced an apparatus based on the same principle, but he does not protect it from the wind, under the belief that, the negative, the objective, and the image being connected together, and the wind or the shaking of the ground making all move together, the image remains motionless. This at first appears very true, but such an arrangement is fatal to the sharpness of the proof. For, in order that it should be correct, it would be necessary that the sun itself moved in the same way, whereas it remains motionless; and therefore, on the least wind or the slightest movement of the ground, all the outlines of the image are seen to be *doubled*, by which defect all fineness in the enlarged proof is lost.

To understand thoroughly this effect, it must not be forgotten that the sun is a fixed luminous point, and that if the optical apparatus happens to move when its axis is directed towards this point, the axis is deranged and the summit of the luminous cone falls more or less on the outer part of the objective instead of on its centre. There results from this a displacement of the image, because the image formed by the central part of the objective and that formed by its margin do not coincide, and are the farther from doing so in proportion as the radii of curvature of the surfaces of the lens are

shorter. (There would be no displacement of the image if the radii of curvature were equal to infinity.) This displacement of the image is not very apparent, and it is this probably which has led M. Liébert into error. But it is, nevertheless, easy to convince oneself of the fact if the ordinary negative be replaced by one having two very fine threads stretched over it and crossing each other. If the point in the enlarged image where these threads cross be marked with a pencil, it will be seen to be displaced (often to the extent of a millimètre) if the apparatus happen to be shaken.

This experiment can easily be made with an apparatus working with a reflector. Select in the enlarged image a point very sharply defined, and mark its place with the point of a pencil. Disturb the position of the reflector, and you will see the point displaced, only to a small extent it is true, but still sufficiently to destroy all the sharpness of the image.

M. Liébert's apparatus, as well as instruments having a reflector, ought, therefore, to be protected from the wind and from any movement of the ground on which it rests, or else, although condenser, negative, and screen may be fixed in a common box, the enlarged image will lose its sharpness. It is the same also with all imaginable apparatus, and to attempt to make it otherwise would be uselessly to deny a mathematical truth.

Fig. 4, plate III., shows M. Liébert's apparatus. A rectangular box, A B, carries at its upper part the condenser, *a*, which is of crown-glass, plano-convex or concavo-convex, and of very short focal length. The frame for the negative, *b*, moves, as in the American apparatus, between the objective, *c*, placed at the principal focus of the condenser, and the condenser. To the box is fastened a cone, D C, at the base of which the enlarged image of the negative is formed. A bellows arrangement, C B, intermediate between the cone and the optical part, permits of a variable length being given to the apparatus, according to the size of the enlargement. This adjustment is effected by the screw *g*.

The whole of the apparatus is supported on a foot, H, susceptible of two movements, one in azimuth by the screw *e*, the other vertical by the screw *f*. But the centre of gravity of the apparatus being placed above the point of suspension causes very great instability, so that the least wind makes the solar camera oscillate about its centre of suspension. To avoid this, it would have been necessary to adopt the plan used in heavy astronomical telescopes, namely, to suspend the apparatus from a point above its centre of gravity, between two uprights, as represented in fig. 5, plate III. Then the equilibrium would have been stable, according to the rules laid down in mechanics. The base, L M, of the apparatus should have been very heavy and of large diameter, as shown in our figure. The two movements, the one in azimuth and the other vertical, are effected by the handles N and O.

Lastly, the greatest fault of this apparatus lies in the short length which is obliged to be given to it to render it manageable, and which can only be effected by giving a very short focal length to both the condenser and the objective. The condenser no longer gives a cone of solar rays terminated at its summit by a well-defined image of the sun, because of the considerable spherical and chromatic aberrations. The objective which has a small diameter does not include a sufficient angle; its margins are covered by some of the solar rays coming from the condenser. This produces the phenomena of diffraction, which have the effect of doubling all the sharply defined outlines of the image—an effect which we shall examine more in detail afterwards.

On the other hand, the apparatus arranged on this system works easily in winter, and does not require a special method of setting up; a point of some advantage in large towns.

We may add that, carrying the most rigid economy into the construction of this apparatus, its inventor has been able to render the price accessible to photographers on a small scale, which aids in spreading the taste for enlargements.

CHAPTER III.

THEORY OF THE FORMATION OF THE ENLARGED IMAGE IN WOODWARD'S APPARATUS.

Much discussion took place in 1860 and 1861 at the meetings of the French Society of Photography, relative to the theory of Woodward's apparatus and on the imperfections possessed by it.

We shall now analyse the principal points of this discussion, which we extract from the *Bulletin de la Société Française de Photographie.*

Theory of M. Claudet.—According to M. Claudet (*Bull. Soc. Franç. de Phot.*, 1860, pp. 249, *et seq.*), who first brought forward this theory, the solar camera realises the following conditions:

1*st.* The objective acts, in enlarging the negative, by its central part, as determined by the diameter of the solar image formed at the focus of the condenser. The image of the sun being nearly a point at the focus of the condenser (and exactly so if the condenser be no more than 8 inches in diameter), it follows that the enlarging objective is, through this fact, reduced to a very small fraction of its aperture.

2*nd.* All the light proceeding from the condenser which traverses the negative and then the objective is *useful* for imprinting the enlarged image of the negative projected on a surface sensitive to light.

3*rd.* The objective acts, in enlarging the image, *according to the law* of conjugate foci.

Observations of M. Bertsch.—M. Bertsch contends that the system of illumination by means of convergent light cannot give sharp images in the enlarged proof. Let us examine the value of his arguments.

In the first place, M. Bertsch says (*Bull. Soc. Franç. Phot.*, 1860, pp. 63, *et seq.*), the non-achromatic lens of large diameter employed as condenser does not give a cone of light of which any section whatever—that, for example, where the negative for enlargement is—represents a circle equally illuminated. This circle is formed by concentric rings composed of rays of unequal refrangibility, the red only being visible at the circumference. Now, these differently coloured rings being unequally refrangible by the objective, the image, though sharp on the negative, cannot be so on the enlarged screen.

This observation is true, and it would be necessary, in order to avoid the defect pointed out by M. Bertsch, to employ an achromatic condensing lens. However, a more profound examination of M. Bertsch's observation proves that the section of the cone of light where the negative is, may, in reality, be considered (except the edges) as a circle of white light, for, if it seem otherwise to the eye, it is not so for photographic substances which are only sensitive to the blue and indigo rays. The most incontestable proof which could be furnished of this fact consists in effecting the enlargement of a network formed of very fine lines traced on a plate of glass, with an ordinary solar camera, in the first place, and then with it when achromatised by means of a blue solution of ammoniacal chloride of copper, as we have pointed out at page 77. The image of the network in the first case, and that in the second, although unequally sharp in appearance, are equally so in reality on the enlarged proofs.

This experiment, which the author of this work has made many times before competent persons, proves on the best evidence that it is not necessary to achromatise the condenser of the solar camera, because the enlarged image has not to be sharp on the screen, but only on the photographic proof.

The second observation of M. Bertsch is not, it seems to us, better founded. We shall let him speak for himself:—"Not to complicate the question, and to confine ourselves within the practical limits of superficial enlargements of five or six times, we shall admit that the convergent rays which emerge from the collecting lens are of white light. On examining these rays after having interposed in their path a plate of glass with parallel sides, we perceive that the caustic curves which limit the focus stretch out very far, and that at the same time the field of light changes in aspect. We have before us a phenomenon of interference. From the centre, where the refraction is nothing, to the circumference, where it is at its maximum, the pencils fall on the glass with very different incidences, so that on their emergence the ratio of their sine of refraction to that of their incidence is changed. They now move less nearly parallel and interfere with each other before reaching the focus. The final result is a fresh disturbance of the equality of the illumination, which is further complicated by the circumstance that the glass which bears the negative never has parallel faces.

"It is sufficient to substitute a microscopic object for the transparent glass, to observe the effect of this new cause of disturbance.

"Blurs of diffraction will form on all the outlines; the details will be vague, and the lines spread out, thickened, and multiplied."

We make avowal, with all humility, of never having ourselves perceived that, on placing a sheet of glass with parallel surfaces in the course of a luminous cone, a phenomenon of interference was produced, the result of which was the production of double lines in the outlines of the enlarged image. In the *Newtonian* telescope—a form of instrument still very common—a concave mirror throws a cone of convergent luminous rays on a prism: now, this prism is evidently a plate of glass not having parallel surfaces, so that there should

be a production of interferences in the image, and consequently imperfection in its sharpness. We think no astronomer or optician has ever suspected or perceived it.

We have many a time made the experiment of substituting for the network formed of very fine lines drawn with a diamond on a sheet of glass, a network formed of fine platinum wires stretched across a frame; but never, when employing comparatively these two networks in the solar camera, have we perceived the disturbance which, according to *M. Bertsch*, the interposition of the plate of glass ought to have produced in the enlarged image of the lines.

We have certainly observed the multiple lines which occur about the sharply terminated outlines of the enlarged image, but we shall show, further on, under what circumstances they occur.

To obviate the defects of Woodward's solar camera, which we have just pointed out, *M. Bertsch* substitutes (*Bull. Soc. Franç. Phot.*, 1860, p. 67), for Woodward's single condenser, two lenses of the same kind of glass, the first, *o* (fig. 76), convergent, the second, B, divergent, and placed at such a distance from the first that the solar rays emerge from the system in the direction *o'r'*, parallel to each other and to the principal axis. In this way *M. Bertsch* says the solar rays will fall normally on the negative to be enlarged, and, therefore, there will no longer be any blurs of diffraction.

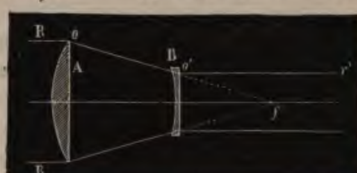


Fig. 76.

That such a system gives a cylinder of rays very nearly parallel is correct, but a section of this cylinder is a circle much more heterogeneous and unequal, as a field of illumination, than that taken in the cone emerging from a single convergent lens. For the chromatic aberration is in this case much more *considerable* than in the system of Woodward.

We believe that *M. Bertsch* has not sent out apparatus with two lenses (at least we have never met with one), and we know that he has replaced this double condenser by the simple rays of the sun, which illuminate the negative normally to its surface. In these conditions the illumination is evidently perfect, but insufficient as regards intensity; a question which we shall examine, however, when treating of M. Bertsch's apparatus used with parallel light.

M. A. Thouret's Observations.—(*Bull. Soc. Franç. Phot.*, 1860, p. 285). Without wishing to examine the influence of the non-achromatism of the condenser, and of the passage of this convergent light, $p\,c$ and $p'c$ (fig. 77), through the negative, N o, this author contends that the enlarged image of the negative will be wanting in sharpness, because the enlarging lens is not limited to its central part, as determined by the summit, c, of the cone, $p\,c\,p'$, of solar rays proceeding from the condenser. For, says M. Thouret, any point, a, of this negative also sends a cone of rays, L a M, to the whole surface of the lens L M; therefore, the lens, in enlarging this point, acts in two ways; firstly, by the solar ray which traverses it, and, secondly, by the rays *emitted* by this point.

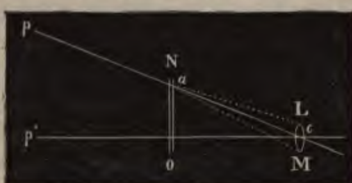


Fig. 77.

To this M. Claudet replies (*Bull. Soc. Franç. Phot.*, 1861, p. 7), that the argument would have weight if the negative arrested the solar light. But it is very transparent, therefore the relation between the light *transmitted* and that *emitted* is such that the latter has no influence (through want of intensity) on the sharpness of the image, and, therefore, that the enlarging lens, L M, may be considered as acting by its centre only. Experience, as we shall presently show, proves that M. Claudet was right.

Theory of M. Foucault.—These are, in the main, the

principal observations made on the solar camera. It is clear, beyond doubt, that the true place of the enlarging lens was that of the summit of the cone of convergent rays. When the discussion (which lasted several months) was terminated, M. Foucault, the distinguished physicist, spoke in his turn, and gave a clear and plain account of the theory of the solar camera, with which we ourselves fully agree (*Bull. Soc. Franç. Phot.*, 1861, pp. 14–16).

"After attentively listening to the explanations advanced by M. Anthony Thouret, I think I noticed that the discussion entirely rested on a confusion of words.

"The small image which, in Woodward's apparatus, it is requisite to cause to fall on the enlarging lens, has never been taken, as M. Thouret supposes, for an image of the negative to be reproduced; it is a real image of the sun, formed by the union of all the rays received by the condenser. This condition being satisfied, it is right to maintain that the enlarging lens acts as if it were stopped down to the diameter of the solar image.

"In fact, let the condenser be C (fig. 12, pl. I.), the enlarging lens L, and the screen E, placed at a distance corresponding to the conjugate focus of the plane N, where the negative is to be placed. In the apparatus thus arranged, and with the negative absent, it is evident that the whole of the light spread over the screen is composed of the same rays, which, at the position of the enlarging lens, are grouped so as to form an image of the sun. This image, therefore, contains in its small extent all the light which, farther on, is spread over the surface of the screen. It follows from this that the entire zone of the enlarging glass which exceeds the solar image could be covered up by a diaphragm, without in any way altering the effect, and without cutting off a single ray.

"Now let a negative be placed in the plane N; the glass which supports it having faces sensibly parallel, the general course of the rays will not be changed; the solar image will

continue to be formed on the enlarging lens; but many of the rays, in their passage through the different points of the negative, will undergo a partial and varied extinction, the effect of which will be reproduced at points similarly disposed on the screen. It is in this way that an enlarged image of the negative is formed solely by the partial and local extinctions that it causes, without in any way modifying the geometrical path of the persistent rays.

"There is, therefore, good reason for asserting that, in the formation of the enlarged image, the region only of the objective occupied by the solar image has any effective influence, that the external zone gives passage to but an insignificant proportion of diffused rays, and that, consequently, the lens cannot by spherical aberration give a wrong direction to the useful rays.

"If it be said that, to obtain the best results, it is indispensable to receive the focus of the condenser on the enlarging lens, it is another question altogether. All that is to be concluded from the preceding explanations is, that everywhere where the bundle of illuminating rays forms itself into an image of the source of light, it may be considered as passing through a diaphragm of the same form and the same extent as this image. From this simple consideration it is easy to foresee the part reserved to the various portions of the enlarging lens, according as the solar image is formed at the position of the optical centre, before it or behind it.

"By making the focus of the solar rays fall on the enlarging lens, it results that only one and the same portion of this lens is affected in the formation of the entire image of the negative, which is not in general a condition favourable to equality of effect.* *Under pretext of avoiding spherical aberration, the more serious inconvenience is fallen into, which consists in a diminution of the field of good definition.* This is a fault inherent in the arrangement claimed by Mr. Woodward, and which does not

* See page 89 and fig. 46.

allow of its being considered as a complete solution of the problem of optical enlargement.

"It would be preferable, in my opinion, to make the solar image, I (fig. 11, pl. I.), fall beyond the enlarging lens, L, on the condition of giving to it the form of a meniscus, of which the concavity is turned towards the solar focus. There would thus be obtained a system which would act in the opposite way to the old form of camera of Wollaston, adopted by Daguerre.

"This arrangement, based on the employment of a single glass, ought, even now, to give tolerably good results; but new resources would still be found in the employment of combined glasses."

This preliminary examination having been made, the reader will have formed some idea of the theory of the formation of the image in Woodward's apparatus; and we shall now, in our turn, examine the theory, and point out its principal defects.

CHAPTER IV.

IMPERFECTIONS OF WOODWARD'S APPARATUS.

Blurs of Diffraction produced by the Circle of Aberration of the Condenser.—When the condenser of the American apparatus has only a small diameter (for example, one of 8 inches) and a rather great focal length (three or four times its diameter, for example), it may then be considered as true that all solar rays emerging from the lens converge towards

a single point, and that there is formed at its focus a sharp image of the sun. If, now, the angle (fig. 78) included by the enlarging objective, M,* is greater than the angle, O, of the cone of solar rays, the whole of the rays striking the condenser are nowhere arrested in their course, and the enlargement of the photographic negative is made with an

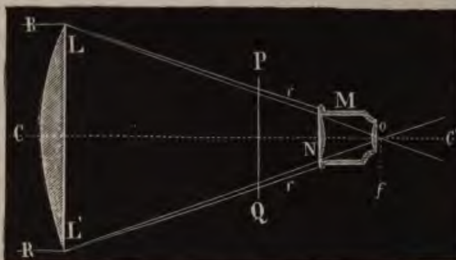


Fig. 78.

admirable sharpness. But in all solar cameras actually made this condition is not fulfilled, the objective not including a sufficient angle;† and this causes, in the enlarged image, *blurs of diffraction*, which are particularly observed when an enlarged image is imprinted on paper sensitive to light: multiple lines are seen to be formed around all the sharply marked outlines of the negative, the trace of which is recognised in the finished proof.

Many persons attribute the doubled outlines of the image to a vibration of the ground by a passing carriage, or else to a displacement of the cone of solar rays, resulting from the imperfection with which the rays of the sun reflected into the apparatus are kept in a constant direction. Such, however, is not the fact; for if it were one of the parts of the apparatus which became deranged—the negative, for example, or the frame which holds the sensitised paper—the multiple lines ought evidently to affect all the outlines in a direction

* We are supposing here the case in which a double objective is used as the enlarging lens, the single objective giving, for this purpose, not nearly such satisfactory results.

† The two lenses forming the objective being too distant from each other.

contrary to the displacement. Now, generally, towards the centre of the image the blurs of diffraction are not perceived; it is especially towards the margins that they are produced.

As to the second hypothesis: when excessive care is taken in managing the reflecting mirror, and even when this is replaced by a heliostat, set and constructed with the greatest precision, blurs of diffraction are produced, and therefore this is not their cause.

With any solar camera whatever, it is easy to produce, *at will*, blurs of diffraction in the following manner. Place before the enlarging objective, and nearly in contact with its surface (which faces the negative to be enlarged), a diaphragm, the aperture of which is a little too small to allow the solar rays emanating from the condensing lens to pass. The enlarged image of the negative appears very sharp upon the screen, but if we proceed to print this image, in a few moments we observe blurs of diffraction produced—particularly if the negative presents well-defined lines—around which multiple lines are formed, which destroy all the sharpness of the outlines of these parts of the proof. By making a negative of the black characters of a book and enlarging them, these blurs of diffraction may be particularly well observed.

The blurs of diffraction will also be observed, and the enlarged image of a negative, P Q (fig. 78), with minute details, will not be sharply defined, if the margins, *r r*, of the cone, L O L′, of solar rays fall on the brass ring which forms the mounting of the objective, M. It is known that if solar rays fall on a convergent lens in the direction of its axis, they will all converge towards the focus, *o*; that a section of this cone, P Q, is a white circle bounded by a red circumference, which is due to the non-achromatism of the lens, L. If these red rays do not pass freely through the enlarging objective, but fall on the mounting, as represented in the figure, though these rays may be quite useless for impressing the image, and though the enlarged image may be very sharp to the eye, still there will be produced, during the printing of the image,

double lines round its sharply marked outlines. This experiment we have made hundreds of times in the open country, on very firm ground, far from all roads and all disturbances, with the solar rays reflected by a heliostat of extraordinary precision, obtained from the celebrated house of Ertel and Son of Munich, and set with special care. These blurs are not produced at all in the circumstances which we have previously enumerated, and of which we are about to treat more fully.

With the primitive apparatus of Woodward, the plano-convex condenser of which is no more than 8 inches in diameter, the blurs of diffraction are not found to appear, and what is most extraordinary is that they only appear when, in order to operate more quickly, the diameter of the condenser is increased, the magnifying objective remaining the same. We worked in 1861 with a condenser of 6 inches in diameter, but it required several hours to produce, on chloride-of-silver paper, enlargements of 40 centimètres by 50. In 1862 we applied to M. Sautter, engineer and director of the manufacture of instruments for French lighthouses, who made for us, for our experiments, two convergent lenses, of 13 and of 20 inches diameter, with a focal length two-and-a-half times this diameter. It was a surprising fact, that these two lenses, employed with the same negative and the same magnifying objective, never gave enlarged proofs nearly so sharp as the small primitive apparatus, the condenser of which was only 6 inches in diameter. Our first idea was to achromatise these lenses by the interposition of a vessel containing a solution of ammoniacal chloride of copper between the reflecting mirror and the condenser, which arrests the red, yellow, and orange rays; but the results were not changed.

These experiments were repeated a great number of times, and gave us, before long, evident proof that large condensers should never have been employed for solar cameras, and that it was not by any means their achromatic defect which was the cause of the want of sharpness (the doubled lines) which they produced in the enlarged image.

A visit to MM. Ghémar Brothers, in 1864, in their magnificent studio for enlarging, in the Chaussée de Charleroi, Brussels, furnished us with a new proof of the correctness of our observations. These gentlemen possessed two of M. Wöthly's apparatus, one of which had a condenser of 9 inches, and the other a condenser of 24 inches diameter. Relatively to the surface of the condenser, the first was much more rapid than the second, but often gave rise to blurs of diffraction from which the second was free. An attentive examination caused us to see that the first apparatus (the condenser of which was 9 inches) sent its entire cone of emergent rays to the objective, and as its focal length *was very short*, the red margins of the cone impinged, as represented in fig. 78, against the edges of the mounting of the objective, which was the ordinary portrait combination.

In the other, the negative holder, P Q (fig. 79), was perforated by an aperture very nearly 18 centimètres square, and the cone, L *f* L′, of solar rays was thus reduced to only a part, *o f o*′, of its section. In other words, the edges of this negative-holder greatly lessened the extent of the condenser. This caused the apparatus to have little power, but it also caused the absence of blurs of diffraction, since the emergent cone of solar rays now passed *freely* through the enlarging objective.

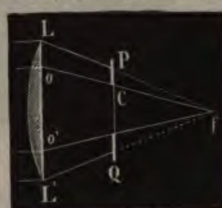


Fig. 79.

An attentive examination of most enlarging apparatus constructed in France, as well as in Germany and elsewhere, soon led us to perceive that the enlarging objective generally had too great a focal length, and such that the negative was too near the condenser, arresting (as represented in fig. 79) a part of the solar rays sent out by the latter; hence the little power of all these apparatus, which required and which still require several hours for printing, on chloride-of-silver paper, a proof 55 centimètres high by 45 broad.

If, on the contrary, the whole surface, L f L′ (fig. 79), of the condenser is utilised, by giving to the enlarging objective a shorter focal length, and such that the negative is placed in the cone of convergent rays, so that the red which bounds it falls on the margins of the objective, then the blurs of diffraction appear during the printing of the proof, particularly if this be of large size; a result due to the fact that the margins of the cone do not freely traverse the objective. The proofs are then deficient in the sharply defined outlines which constitute the beauty of a proof, particularly of a view, and these proofs most frequently require much touching up.

From what precedes, every intelligent reader will understand that which we ourselves have comprehended, namely, that it was necessary to give up in the condenser a short focal length, and to give to it, L L′ (fig. 80), a very considerable

Fig. 80.

one, L M, at least five or six times its diameter, if this diameter be more than 14 inches. But then the objective, M, ought also to have a great focal length itself; for the negative, P, must be very far away from it, if its whole surface is to be illuminated. The enlarged image must then be projected a distance of several mètres, and, in employing under such conditions a condenser 19 inches in diameter, the camera that would be necessary for a proof one mètre square would be 12 mètres long. It will be seen, therefore, that this system, which, on the whole, would be the best in all respects, cannot be employed in the conditions under which most photographers are placed.

In order to avoid this inconvenient length, we had made, towards the end of 1863, some negative lenses, N N′ (fig. 81),

which, placed in the path of the cone, L f L′, of solar rays emanating from the condenser, L L′, increased the focal length

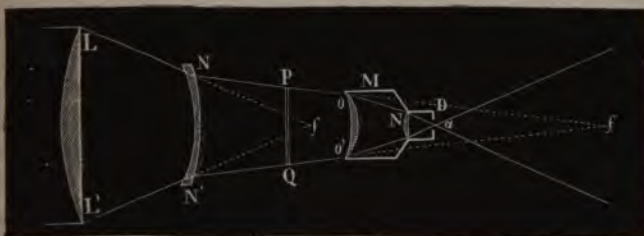


Fig. 81.

from f to f'. The objective, M,* had a great diameter, $o\,o'$, in relation to its focal length, and such that it could be brought near the negative, P Q, so as to throw the image to a shorter distance. This apparatus, however, did not produce a good result. An attentive examination led us to see that the *spherical* aberration (and not the chromatic) of the system L L′, N N′, was very considerable, and that it was impossible to accurately limit the bundle, a, of emergent rays, by a diaphragm, D, even by achromatising the system by a vessel of ammoniacal chloride of copper. It was at this period that we had systems of condensers made completely free from this aberration, which have ever since given us proofs of remarkable sharpness.

The cause of the doubled lines in the solar camera with one condenser, appears therefore to us to be due to the great spherical aberration of these condensers. When, in fact, it is considered that these lenses of plano-convex form are 30 and 36 inches in diameter, and that their focal length is generally less than twice their diameter, and often only once and a half their diameter, an exact idea can easily be formed of the great value of the circle of aberration, the diameter of which increases with the *cube* of the aperture (see

* The objective had the form of Ramsden's eye-pieces in telescopes of large field called *comet-finders.*

p. 66). What follows from this, even on artificially achromatising such a condenser (whether we suppose it so or interpose a vessel of ammoniacal chloride of copper)? That the enlarging objective, even when we give it a considerable diameter, always arrests a certain part of the rays emergent from the condenser, particularly those which emerge from the margin, on account of the large diameter of the circle of aberration; and even should the objective be placed where the circle of aberration is the least—a condition which can hardly be realized in practice—still this phenomenon would be produced.

On the contrary, with a condenser free from spherical aberration (through the addition of a divergent lens of suitable curvatures), these blurs of diffraction are no longer produced, the rays emergent from the condenser all now cutting the axis at the same point, and thus passing freely through the enlarging objective without being arrested by the sides of its mounting.

The principal defect of the solar camera, as first constructed by its inventor, arises, therefore, not from its want of achromatism, but from this rather, that, if we suppose incident rays of one order only—those which affect chloride-of-silver paper, namely the blue and the violet—they cut the axis at different points, and thus there is produced at the focus of the condenser an image of the sun surrounded by a round aureola, the diameter of which increases as the focal length of the condenser is shortened.

We can conceive (but not execute in practice) a *single* enlarging objective (achromatic, however, otherwise it would have a chemical focus) which would include all the rays emergent from the condenser, designed by M. Léon Foucault, as represented in fig. 11, pl. I. But up to the present time single objectives, as enlarging lenses, have not given good results. Generally the field of the enlarged image is curved—that is, it is deficient in sharpness at the edges—and further, the *distortion* of the image is the greater, according as these objectives have a shorter focal length.

As for the doublet-system of Petzval* (the ordinary double jective), the angle included by it being greater, and its field tter, it gives, when employed in the solar camera, better sults than the single objective. But if it be placed in the is of a condenser, of which the circle of spherical aberra- n is considerable, even if the first, N (fig. 78), of the two ıses (that facing the negative) should include all the rays ıergent from the condenser, these rays would only in part ike the second lens, *o*. The experiment is very easily ide, and then on the centre of the first lens of the doublet, e circle of light will be seen surrounded by red; and the second, which faces the screen, the image of the

Fig. 82.

n surrounded by blue—of which a part (that emerging om the margins of the condenser) is arrested by the mounting the objective. And therefore this objective, particularly hen modified as we have described it further on, only gives tisfactory results on the condition of being associated with condenser of which the circle of aberration is of slight iameter.

To thoroughly understand how it is that the form of the ɔjective cannot be made to bend to necessity, it must not be

* The triplet of Dallmeyer, and still more the globe-lens, is inferior for is purpose.

forgotten that the best size for the negative being given, there exists between the distance from the negative, P Q, to the optical centre, C, of the enlarging objective, and the distance from this point, C, to the screen, N M, on which the enlarged image of the negative is projected, a fixed relation (that of the conjugate foci) which thus determines the enlargement, that is, the ratio of the size of the negative to that of its enlarged image—of P Q to N M.

Illuminating this negative, P Q, by diffused light, or by convergent solar light, the distances from P Q to C, and from N M to C, remain invariable. Now, if it is wished to illuminate the negative, P Q, by convergent light by means of condensers, L, L′ or L″, the focal lengths of these condensers must be such that the angle of the cone P C Q remains always exactly the same, whatever may be the diameter of the condenser.

It will consequently be seen that with a small condenser, L″, or a very large one, L, the results ought to be identical as to sharpness, and in the ratio of L^2 to L''^2 as to rapidity. But if L″ has a small diameter, its circle of aberration will be small and may therefore be less in diameter than the enlarging objective, C; if it is considerable, its circle of aberration, which increases as the cube of its aperture, becomes greater in diameter than the objective; and hence blurs of diffraction are produced.

It would, therefore, be necessary to enlarge the diameter of the amplifying objective, C, whilst preserving its focal length, P C, and this in proportion as the condenser becomes larger. Now, every one knows that this is not practicable, and that there exists between the diameter of an objective and its focal length a relation learnt by calculation and experience which the optician must perforce observe.

If it is impossible to make enlarging objectives for large condensers with short focal lengths, it is, on the other hand, possible to make large condensers, the emergent rays from which are *practically* and *really* all in the condition required by

figure 82. It is sufficient for this to destroy their circle of spherical aberration by destroying this aberration itself. Then, the size of the negative remaining fixed, the objective which enlarges it remains also fixed, whatever may be the diameter of the condenser.

Imperfections of the Objective.—The observation pointed out by M. Thouret, and of which we have spoken at p. 174, though refuted by M. Claudet, is not the less true in practice. The negative, if it is very transparent, certainly allows nearly all the solar light falling on it pass through. But very often the negative is less transparent than it ought to be, and the sun, through the interposition of slight clouds, often gives, particularly in our climates, less light than usual. Thus a given point in the negative is reproduced by the objective in two ways—firstly, by the solar light which traverses it; and secondly, by that which it gives out. The more intense the negative, and the weaker the light of the sun, the more this is true. In the first case, the objective acts by one point of its surface, and in the second by all its surface, and these two images are neither concordant, nor equally sharp, particularly at the margins of the image.

Any one who possesses an ordinary solar camera can easily satisfy himself of this. Focus on the screen a very sharp negative. You will remark that if a cloud veils the sun the margins of the image want sharpness (which sharpness increases by diaphragming the enlarging objective), and that, according as the sun gets clear of clouds, the sharpness at the margins considerably increases and remains the same with or without diaphragms on the enlarging objective. On placing a ground-glass between the condenser and the negative the image loses in sharpness *at its margins;* on withdrawing the ground-glass, the image not only becomes brighter, but much sharper.

This demonstrates that the objective (we speak here of the ordinary double lens) does not act in the solar camera as usual. For in the *solar camera* each point of the negative to be

enlarged may be considered as traversed by a single pencil of solar light; therefore an infinitely small fraction of the enlarging objective forms the image of this point on the screen. Ordinarily a point of the plane to be reproduced sends to the objective a bundle of light, of which the entire aperture of the objective is the base and the point the summit: consequently it is the entire objective, or at least the part of its surface that the diaphragm does not cover from the point, which forms the image of that point. The two cases are very different, and therefore an objective, although excellent as the enlarging objective of a solar camera, may be of no value as an ordinary objective, and conversely.*

The necessity that exists for leaving the objective with a diameter as large as possible, in order to give passage to all the rays emerging from the margins and from the centre of the condenser, has, as M. Bertsch and M. Thouret have very properly observed, the effect of fogging the proof, because the rays emitted by the points of the sky, bordering on the sun, pass through the objective like the solar rays themselves. Experience has taught us that in the ordinary solar camera this defect is of very little importance in very clear weather, when the sun shines with his full brightness, and the negative to be enlarged is very transparent. But if the sky is cloudy, if the sun is veiled by light clouds, or if the negative is a little too intense, the whites of the enlarged image are always discoloured by the diffused light thrown out by the objective. If the objective be diaphragmed, diffraction is produced, which destroys the sharpness of the image (that is, with the ordinary systems of condensers).

This is why, in the construction of the solar camera, we have abandoned the form of the double lens and adopted another (based, however, on the data of M. Petzval) of which M (fig. 78, p. 178) is an accurate representation.

This objective has a form such that the image of the nega-

* This is why the *triplet*, the *orthoscope*, the *globe-lens*, &c., are all very *inferior to Petzval's* combination, even with equality of aperture.

tive is equally sharp, whether illumined by solar or diffused light. Further, to avoid the diffused light of which we were just now speaking, and which has the effect of fogging the enlarged image, the lens, *o*, facing the screen, is just large enough to let the image of the sun pass, and intercepts all light coming from the points of the sky bordering on this body.

Suspension of the Negative.—The third imperfection of Woodward's solar camera consisted in the way in which the negative was placed in the cone of solar rays. It was fixed in a square or rectangular frame, and was traversed by the rays of the sun, which heated it in proportion to the density of the negative. The margins of the negative remaining cold (for most often only the central part of the negative was traversed by the solar rays), it became unequally expanded, and fractured in consequence.

This imperfection, like the two others, was of little importance in the original American solar camera, the condenser of which was only eight inches in diameter, and in which, therefore, the heating of the negative was not considerable. But it was otherwise when large lenses came into use; and nine out of ten negatives broke when the condenser had a diameter of from 19 to 24 inches. M. Delessert, who had a solar camera of which the condenser, 80 centimètres in diameter, broke all the negatives, was obliged to keep them cool by directing on them a strong current of air produced by a ventilator. M. Verbecke, of Louvain, without knowing the remedy of M. Delessert, found it out for himself, and also employed it; but he made use of organ-bellows instead of a ventilator.

By suspending the negative so that it is heated equally all over its surface, this inconvenience is avoided. We shall describe this mode of suspension in the following chapter.

CHAPTER V.

THE DYALITIC APPARATUS.*

Differences between it and the ordinary Solar Camera.—The dyalitic apparatus—a name which we have given it because of its analogy *in form* with the dyalitic telescope—differs from Woodward's solar camera in the three following points:—

1st. The condenser is corrected for spherical aberration, so that, taking only one order of incident rays into consideration, all the rays emerging from the condenser cut the axis at the same point: this prevents the blurs of diffraction.

2ndly. The negative is suspended in the apparatus in such a way that it no longer breaks under the heat of the solar rays.

3rdly. The objective has a peculiar form, better suited for enlargement than that of the single or the double combination, the enlarged image being sharper and free from mistiness.

Summary description of the Dyalitic Apparatus.—The adjustible mirror (figs. 1, 2, 5, pl. II.) is composed of a finely polished and perfectly silvered glass, supported by a framework of iron or wood, which prevents it bending. This glass is a little larger than the diameter of the condenser, and two-and-a-half times as long. The axis which supports it passes through its reflecting plane perpendicularly to its length in such a way as to render its equilibrium stable. The glass can take all imaginable positions about this axis by means of a toothed wheel fixed on its axis of rotation, this

* *Vide* tome X. du Bull. Soc. Fr. de Phot.—'*Mémoire sur un nouvel appareil dyalitique pour agrandissements photographiques.*'

wheel being governed by an endless screw, the rod of which passes into the dark room in which is the optical apparatus. The axis which supports the mirror turns between two horizontal arms attached to a disc revolving in a vertical plane, and also receiving its motion from inside. The mirror can therefore take, in relation to the sun, all the positions necessary for sending his reflected rays horizontally into the optical apparatus.

The reflector is fixed in the shutter of a room, suitably darkened, in front of the solar camera.

The optical apparatus (fig. 4, pl. II.) is composed of a box, on the front of which is fixed the condenser, the diameter of which is 19, 14, or 8 inches, according to the power it is wished to have. This condenser is *bi-convex;* the face turned inwards being nearly plane, and that turned outwards very convex. Its curvatures are such as to reduce its spherical aberration to the minimum. At a distance from this lens, equal to its diameter, is a concavo-convex lens, the concave side of which faces the condenser. The diameter of this negative lens is a little more than half that of the condenser; its thickness is very slight—only 6 or 8 millimètres—in order to absorb as little light as possible. The effect of this lens is to completely correct the spherical aberration of the condenser, so that the cone of solar rays emerging from the negative lens has a single point of the axis for its summit.

These are the numerical data of this combination, expressed in terms of the semi-diameter of the condenser, taken as unity.

1st surface R	= 2·645	Thickness at the centre ..	0·196
2nd surface R'	= 21·639	Focal length	4·015
3rd surface R''	= 1·083	Thickness at the edges ..	0·067
4th surface R'''	= 1·234		

Distance between the two lenses ..	2·0075
Focal length of the combination ..	4·617
Index of refraction (blue)	1·543

In the path of the cone of solar rays is the negative. This

can be moved in the direction of the optical axis so as to be moved towards or away from the condenser.

At the focus of the illuminating system is the *amplifying objective*, which has a common axis with the condenser and the correcting negative lens. This objective has the external form of Ramsden's eye-pieces placed on pocket telescopes, but it is constructed on the principles of M. Petzval's doublet. It is completely free from spherical aberration along its axis and from chemical focus.

The diameter of the two lenses which form it is different, the largest lens being towards the negative. The object of this difference is to prevent the objective throwing over the sensitive paper, by diffusion, some of the light coming, not from the direct solar rays, but from the points of the sky bordering on the sun. An objective, the two lenses of which had the same diameter, but of which that facing the enlarged image was furnished with a diaphragm, would effect the same object.

The author of this work has had constructed several of these objectives having different diameters and focal lengths; but all these objectives still include an angle, $s C t$ (fig. 82, p. 185), greater than the angle of divergence, A C L, of the cone of solar rays emergent from the condenser. Theoretically, it would be sufficient if the angle included by the objective were equal to (but in no case smaller than) the angle of divergence of the cone of solar rays; but then the objective ought to be placed immoveably in the apparatus, or else, in advancing it towards the condenser, the edges of the solar cone would fall on the margins of the objective, and the sharpness of the enlarged image would be injured by the production of blurs of diffraction. Great inconveniences would result from this in practice, because the place of the negative (the dimension of which is variable) in the cone of solar rays is exactly determined by the diameter, $p q$, P Q, $p' q'$ (fig. 82), of the section which corresponds to the largest dimension of the negative, in *order to* profit by all the solar light emanating from the illu-

minating system. The place of the negative being thus determined, it would be necessary that the focal length of the objective should be just that necessary for throwing the enlarged image sharply on a screen of which the dimension is determined by the sizes of paper made use of in photography. Now, as these conditions do not occur one time in a thousand, it would be necessary to make the negative itself moveable, as Woodward does. But in advancing the negative towards the condenser all the light is lost which falls outside its surface; and in advancing it towards the objective the image is confined to the part of the negative traversed by the solar rays.

The angle of divergence of the amplifying objective, its focal length, and the dimension of the negative, ought therefore to be in relation with the angle of divergence of the cone of solar rays, and, in order to permit of the amplifying objective being moved some centimètres on the axis of the apparatus—a condition indispensable for varying its distance from the negative—a much more considerable diameter is given to that one of the lenses forming it which faces the negative, in order to increase the angle which it includes, and thus to prevent the edges of the solar cone striking against the edges of the mounting.

The angle of divergence of the three sizes of the dyalitic apparatus determined by that of the condensers, which are 8, 14, and 19 inches, being equal for all three; further, having chosen 6½ centimètres by 9 as the size of the negative, the size called *carte-de-visite;* and lastly, having supposed that the linear enlargements would be limited to between 4 and 12 times, we have proved by calculation, confirmed by experiment, that the objective which answers best for the enlargement in the conditions enumerated above is the following:*—

* When the condenser is only eight inches in diameter, the amplifying objective may have a less diameter, the red circle which surrounds the cone of convergent solar rays being less. These are the dimensions adopted for this objective—which we shall name by the letter A, in order to distinguish it from the others, which we indicate by B, C, &c.:—

	Millimètres.
Diameter of the lenses opposite the negative	63
„ „ „ enlarged image	45
Distance between the two lenses	85
Focal length of the combination *	150

This objective is called B.

It happens very frequently that the negative, although formed on a glass of 6½ by 9 centimètres, is smaller than this. This happens particularly when only a part of the negative has to be reproduced. It is then necessary to reduce the negative to the part indicated by cutting it. The place of the negative in the cone of solar rays is then brought considerably nearer to the focus of the condenser, so that the objective can no longer be conveniently employed. For this purpose, we have had constructed a second form indicated by the letter C, the two lenses of which have the same diameter, namely, 63 and 45 millimètres, but which are brought much closer together, and have a focal length of only 12 centimètres.

This objective includes, therefore, a still more considerable angle than does the objective B; it could also serve, therefore, to enlarge negatives of 6½ centimètres by 9, and it would throw their enlarged image to a much shorter distance than B does, but the image would then be less sharp at its edges. The objective C is specially suitable, therefore, for negatives of at least 4 centimètres by 5, and of at most 5 by 6. The objective B is, on the contrary, suitable for the enlargement of negatives of at least 5 centimètres by 6, and of at most 6 by 8.

Lastly, if negatives larger still, and included between 7 centimètres by 10 and 12 by 15, are to be enlarged, we have

	Millimètres.
Diameter of the lenses facing the negative	60
„ „ „ enlarged image ..	40
Distance between the two lenses	55
Focal length of the combination	114

* Reckoned along the axis from the principal focal plane to the tangent plane of the lens facing the focal plane.

a fourth form, named D, of which these are the dimensions :—

	Millimètres.
Diameter of the lenses facing the negative	81
" " " enlarged image ..	50
Distance between the two lenses	110
Focal length of the combination	183

If it were required to enlarge still greater negatives, forms could easily be constructed on analogous data.

It is clear that, since the place of the objective along the axis of the apparatus varies, the space, $x\ x'$ and a (fig. 4, pl. II.), covered by the solar rays is variable. In the position indicated by fig. 4, pl. II., it is very small at a, and the central part only of this lens is traversed by the solar rays. To avoid the diffused light which the points immediately bordering on the sun send through the outer part of this lens, diaphragms are employed. Their diameter necessarily varies according to the position of the objective, and it is necessary to avoid using them too small, or the magnified image will exhibit blurs of diffraction. Generally, with a very active solar light, these diaphragms are unnecessary; but if the sun is slightly clouded, they are indispensable (*vide* p. 187).

This, then, is the description of the dyalitic apparatus, at least from a purely scientific point of view. It remains for us to give a description of this apparatus in its practical aspect; and this will assist the reader in setting up other arrangements.*

* Before commencing to do so, we may be permitted to insist on some experiments, which we have many times repeated, with the object of assuring ourselves if the different improvements made by us in the primitive solar camera of Woodward are really useful. We shall here only occupy ourselves with the introduction of the negative correcting lens, and of the amplifying objective, setting aside the mechanical improvements as of less importance.

A question we have often had addressed to us is this:—"Do you believe that the negative lens is really quite indispensable, and that it is not enough for the condenser to have such curvatures as to reduce its spherical aberration to the minimum?"

And again :—"*Does not* the ordinary double lens, as constructed by good

opticians, serve to magnify the image better than, or at least quite as well as, the objective which you employ—an objective in which you so greatly increase the front glass—a circumstance certainly increasing the angle included by the objective, and rendering the field flat, but which enormously increases the *astigmation*?" (*vide* p. 139.)

Here is our reply:—

Certainly, by substituting for the old plano-convex condensers, with short focal length (they are still in use at present), a condenser with a focal length three times its diameter, and by giving it suitable spherical surfaces, the blurs of diffraction in the enlarged image, which have the effect of destroying its sharpness (*vide* p. 178), can, up to a certain point, be avoided. But this is only true on the condition that the condenser does not exceed 8 or 10 inches in diameter, the negative to be enlarged being of *carte-de-visite* size. Thus it is that on removing the negative correcting lens from the dyalitic apparatus, the condenser of which is 8 inches, results are obtained not sensibly different from those obtained with the correcting lens, which is explained by the small diameter of the lateral circle of aberration of a lens of 8 inches, having 16 or 20 inches focal length. But the results are very different if a condenser is used of 14, and above all of 19 inches diameter. If the negative lens is removed from this apparatus, the image does not *to appearance*, lose in sharpness, but when the image is printed blurs of diffraction are *always* observed: these, on the contrary, are never seen with the apparatus when the negative lens is in place, in which case the images are of remarkable sharpness, particularly striking when a successive and increasing series of enlargements are compared. The appearance of these proofs causes those who see them to say that the fineness increases with the enlargement. It is very different with the common solar cameras, which all produce sufficiently good results in the slight enlargements, but utterly bad in the great enlargements.

This result is explained by the considerable circle of aberration of large condensers. Whenever the correcting lens is taken out of the apparatus, particularly if the condenser is 19 inches in diameter, there is an insurmountable difficulty in placing the objective in such a way as that the inside of its mounting does not receive some of the sun's light, an evident proof of the irregular path of the solar rays through the objective. And even in the position of the objective in which this defect is the least apparent (that of the least circle of aberration), the sharply marked outlines of the image are seen *to be doubled* during the printing of the proof.

All the summer of 1864 we had two apparatus exactly the same, of 19 inches (only that one had its correcting lens suppressed), standing side by side, and capable of working simultaneously. Whenever we received a visit from an amateur or from a scientific man, we caused the two apparatuses to operate on identical negatives, and the dyalitic apparatus *always gave the sharper* results. The only exception was when the negative was not

fine, and had not very sharply marked lines: there was then, however, no means of making a regular determination.

It rests therefore positively beyond question in science that the convergent illumination in photographic enlargements must be free from spherical aberration, as otherwise double lines *always* appear, unless the value of the aberration be an extremely small fraction of the diameter of the objective, which is only the case if the condenser, with proper curvatures, is less than 10 inches in diameter, and that its focal length is more than two-and-a-half times its diameter.

Indeed, even if the condensing combination should be free from spherical aberration, good results as to sharpness would not be constantly obtained, if the ordinary double lenses were made use of, particularly those called in commerce "*quarter and sixth.*" We know perfectly that by very greatly increasing that one of the lenses of Petzval's doublet which, employed under ordinary circumstances, faces the ground-glass, we preserve all the astigmation arising from the oblique position of the two lenses in relation to the incident rays. But observe that a considerable and profound difference exists between the objective as we employ it and as it is employed in the usual camera. In the latter case every point of the object to be reproduced sends to the objective a bundle of light, the angle of which is determined by the aperture of the objective and the distance of the radiating point. The astigmation, therefore, arises from the obliquity only of the radiating point, and if the lens of the doublet facing the ground-glass transmits to the focal plane all the rays emergent from the first the astigmation will certainly be intolerable. But there is nothing like this here. In fact, it is necessary to fully consider that every point of the negative is traversed by a *single solar ray*, which, on reaching the objective, passes through it. You can, therefore, cover with impunity such part of the surface of the objective as you may wish, by an opaque screen, without producing any confusion in the points of the image not cut off by the screen. It is sufficient, therefore, for the objective to be perfect, that it be quite free from both chromatic and spherical aberrations, *along its axis*, and that its focal length for oblique pencils be equal to that for axial pencils. Neither aberration of thickness nor astigmation is possible in this case, and the most evident proof of this we can give is, that the objective we make use of as the amplifying objective—though possessing these two imperfections to a considerable degree if we make use of it to obtain proofs with the camera obscura—gives, in enlarging, images in which the straight lines are rigorously preserved, and in which not a trace of astigmation is to be discovered.

CHAPTER VI.

DESCRIPTION AND SETTING-UP* OF THE DYALITIC APPARATUS, AND IN GENERAL OF ALL APPARATUS FOR ENLARGEMENTS.

The premises intended for the Apparatus.—The first condition for the proper setting-up of apparatus for enlargments, of whatever nature they may be, is to choose a place, the floor of which is as far as possible protected from the vibrations of the ground. If the building is solidly constructed, the passage of carriages does not at all interfere with the sharpness of the proof. Thus, the author of this work has seen the dyalitic apparatus in operation at the establishments of M. Franck de Villecholle, Rue Vivienne, Paris, and of M. Alexandre Ken, Boulevard Montmartre, Paris—places where the continual passage of vehicles is undoubted—but where the solidity of the buildings is such as to preserve the apparatus from the vibrations of the ground.

The place of operations ought to be 5 mètres long, if it is desired to work with sheets of paper 120 centimètres high, a size very considerable, and one sufficient for the majority of professional photographers. The flooring ought to be rendered as unyielding as possible before fixing the apparatus upon it. If the flooring is altogether deficient in firmness, have two pieces of timber, F and H, 20 centimètres thick by 35 broad, let into the wall, in the way represented in fig. 83, and rest upon them all the parts of the apparatus. These two pieces of timber must not be in contact with the floor, but

* Plates II. and III. represent, with great accuracy, the summer and winter arrangement of the apparatus No. 3. They are drawn to the *scale of 5 centimètres to the mètre.*

3 or 4 centimètres above it. We can then walk about the place without any fear of causing any movement of the pieces of the apparatus; otherwise we must avoid doing so as much as possible.

The wall A (fig. 83), which is perpendicular to the length of

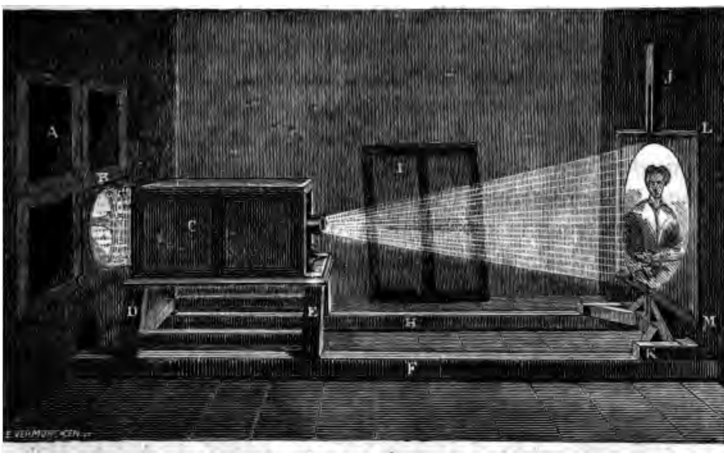


Fig. 83.

the camera, ought to face the *south* as nearly as possible, and receive the adjustible mirror. At least this arrangement is the most favourable, for the sun is then available all day long, if neighbouring objects form no obstacle. Moreover, when the aspect is towards the south-east, the mirror is not long enough in the afternoon, particularly in winter, and when towards the south-west, it is not long enough in the morning. It is therefore necessary to give the adjustible mirror and the apparatus as much as possible a north and south aspect, the mirror being towards the south.

The general disposition of the setting up of a solar chamber (whatever its plan may be) is represented in fig. 83. A is the darkened window exposed to the south in which the

adjustible mirror, B, is inserted, and opposite this is the solar camera, C, on a stand, D E. The enlarged image of the negative is projected on a frame, L M. Let us now pass to details.

Description of the Adjustible Mirror.—When the mirror is of large size it is well for it to be mounted entirely in iron. This is, at least, the plan we have adopted after a long experience. For the adjustible mirror to be well constructed three conditions must be fulfilled. It must present a stable equilibrium such as to resist the action of the wind; the centre of motion must correspond to the centre of figure or be symmetrical with it, in order that the mechanical force required to move it be the least possible; and thirdly, the glass must be supported by a framework which prevents it *bending.* The last point in particular is of great importance, if it is wished to obtain a round image of the sun at the focus of the condenser instead of an elongated image, such as is obtained if the mirror in consequence of flexion is curved instead of being plane. These conditions are rigorously fulfilled in the form of adjustible mirror we have adopted, and of which fig. 1, pl. II., is a representation.

The glass, A B, is rectangular, or, rather, octagonal, the corners being cut off. The iron frame on which it rests is shown separately in fig. 2. This frame, which can also be made of good and well-seasoned oak, carries four projecting pieces of iron, C D E F, between which the glass is placed on the well-levelled surface of the frame, and by which the glass is prevented from sliding off the frame when it is in a vertical position.

Four other catches, of which the extremities are bent at right angles, can be adopted to glasses of any thickness whatever between 5 and 10 millimètres. These catches are fixed to the iron frame by screws of the same metal. The two bars, O and N, give great solidity to the frame.

The support, G H (fig. 2, pl. II.), is of cast-iron, and is screwed to the frame in such a way that the silvered part of the glass passes *exactly* through the axis of the pivots G and

H, as is seen in the figure. This support has pivots, G and H, at its extremities, on one of which, H, is fixed the toothed wheel, I, of bronze. *In order to make the frame and wheel,* I, *quite solid, a screw fixes the wheel to the support.* This is indispensable, for else the wheel, which, as we shall see directly, receives its motion from a pinion, might turn without carrying the frame with it. And it is accordingly quite indispensable to ascertain if this takes place, for if it does a second screw must be employed.

As we said at first, a wooden frame may be substituted for the iron frame, and instead of making the endless screw work the pinion directly, another wheel may be employed, as shown in fig. 3, pl. II., in such a way that the endless screw, *m*, acts on the pinion, *n*, and this on the large wheel, *o*, placed on the axis of the frame which bears the mirror. In this case the movement is slower; but it is necessary to be careful to fix the circle, *o*, on the frame, B, by a screw, *a*, for else the frame, B, would turn freely about its axis.

S U V X (fig. 1, pl. II.) is a frame of cast-iron turned in a lathe on both its faces, and presenting a large, ledged aperture, X X, in which turns the annular disc, Z Y, toothed at its circumference. The cast-iron frame has holes at its four angles by which it may be fixed to the shutter of the dark room. The two arms, *a b*, *c d*, are fixed on the ring, Y Z, by six rivets, and the latter, toothed through its whole circumference, and receiving its motion from a pinion, X, carries along with it also the two arms at the extremities of which are the sockets into which the pivots of the frame of the mirror fit, as will be at once understood on looking at the figure.

Lastly, an iron rod, R *e*, traverses the ring, Y Z, and the base of the arm *b a*. It is terminated inside the dark room by a brass knob, R, and at its other end by an endless screw, *e*.

When the adjustible mirror is completely mounted, as it is seen in fig. 1, pl. II., it is necessary to prevent the extremities of the iron frame, A B, from striking against anything, the

effect of which would be to twist the end of the rod, R *e*, which bears the endless screw. Then, on turning the knob, R, great resistance would be experienced during one half a rotation, and great facility during the other. The bent extremity, *e*, of this rod is easily straightened in the position where a notable resistance is found on turning the knob, R, by pressing strongly but gradually on the lower part of the iron frame carrying the glass, which causes torsion of the rod in the opposite direction. But in all cases it is necessary to act with precaution if we wish not to deteriorate this part of the instrument.

The sockets which terminate the arms ought to be tight, but not too much so, in order that the pivots on which the frame of the mirror turns do not experience too much resistance.

In order to avoid the loss of motion which always occurs between the endless screw and the toothed circle, I, a weight of from 2 to 4 kilogrammes may be suspended from the lower part of the mirror; but in the majority of cases this is not indispensable if the different parts of the adjustible mirror are well adjusted. The adjustible mirror ought evidently to be kept in order like other machines, by dismounting it occasionally in order to oil it, and remove any rust which may have formed on it. The toothed circle in particular must be kept well oiled.

The glass ought to be thoroughly well silvered, and painted beneath. For further security, tinfoil, such as is wrapped about chocolate, may be pasted on the painted surface, which will preserve the silvering still better than the oil-paint which covers it.

The margins of the glass ought to be covered up with black paper, fastened on with paste, for otherwise it frequently happens that coloured lines (rainbow colours) are seen in the enlarged image, arising from the dispersion of the solar rays by the edges of the glass.

The glass itself ought to be cleaned every eight days with

alcohol and a cloth covered with tripoli, and every morning with a dry cloth. In the course of the day it is necessary to frequently remove the dust blown over it by the wind with a long-haired brush, otherwise the printing of the enlarged image might require a much longer time.

Lastly, the glass ought to be sheltered from the rain, or else it would become covered by the end of some months with yellow stains in the silvering, which would cause the expense of a fresh silvering of the glass.*

The management of the adjustible mirror is extremely easy. As the sun advances from east to west, and as further he continues to ascend from his rising until noon, and then descends till he sets, it is necessary to communicate two movements, the one to the handle L (fig. 5, pl. II.), which has the effect of bringing the longer side of the glass into the plane of the solar rays, the other to the knob, P, which gives the glass the inclination suitable for reflecting the solar rays horizontally, and perpendicularly to the surface of the frame, K C.

A cylinder of reflected solar rays which entirely fills the opening K C is thus obtained. We shall see afterwards how the solar rays are kept reflected in an absolutely constant direction.

Setting up of the Adjustible Mirror.—The setting up of the adjustible mirror is extremely simple.† Choose a window, A X (fig. 5, pl. II.), of the apartment, the glazed part of which descends as nearly as possible to the floor, and substitute for the casement a strong deal-board, two inches thick, in which you contrive a ledged aperture of one centimètre, into which the cast-iron frame of the adjustible mirror exactly fits. Four small wedges then suffice to hold it so that it cannot fall into

* Done very well in Brussels, at Nyssens and Co., looking-glass makers, Laeken.

† It is represented with very great accuracy in pl. II., fig. 5, showing, *reduced to a twentieth*, the adjustible mirror No. 3; fig. 4, the optical apparatus; and figs. 6, 7, and 8, the proof frame.

the room.* To the outside of the board attach the wooden flap, B F, moving on a hinge, J. This flap, covered with thin zinc, ought to be a third longer than the mirror, and a third broader, and the hinge is to be only a few centimètres above the upper part, D, of the opening. A cord, G H I Q, enables the flap, to be raised so that it may not in any way impede the movement of the mirror.—(*Vide* fig. 10, pl. II.) Two small side-flaps, E, E (figs. 9 and 10, pl. II.), shut in at the sides the space about the adjustible mirror, which may be left open below. These small flaps, which are shown closed in fig. 9 and open in fig. 10, are moved by cords.

Fig. 5 shows the position of the mirror, S R, when the flaps are closed, a position in which the glass faces the ground instead of the sky, as when using the light from it. This position is obtained by turning the handle L until the axis of the mirror is horizontal. In this way the adjustible mirror need not be taken in to protect it from the rain. The board, A X (fig. 5, pl. II.), ought to be level with the adjacent wall outside, Z Y, unless it is as broad as the mirror is long, and presents a length below the opening equal to half that of the mirror. For if an obstacle were to be there, it might prevent the motion of the mirror.

An important condition, when setting up the adjustible mirror, is to place it as near as possible to the floor, and perfectly vertical. Generally the lower part, C, of the opening ought to be 80 centimètres from the floor, X—the handle L being at the upper part of the opening (either to the right or left). If for any cause we are obliged to place it more than 80 centimètres from the floor, it is then preferable to have the handle L at the lower part, C. The frame of the adjustible mirror being square, the handle can be brought at will either below or above, and to the right or the left, of the iron frame.

* Fig. 5, pl. II., represents the adjustible mirror, K C, inserted into another wooden frame, D N, moveable on the hinges, N O. By this means (vide pl. III.) the adjustible mirror can be inclined, which is indispensable in winter.

If the apparatus is placed on beams as we have figured it at page 199, then the height of the lower part of the cast-iron frame of the adjustible mirror ought to be 80 centimètres above the upper part of the beams.

Description of the Solar Camera.—We have already described the dyalitic solar camera and the American solar camera from a scientific point of view. We shall now describe them from a purely practical point of view, without, however, dwelling on the latter. But this has to be constructed in the same manner as the former, save that the double condenser is to be replaced by a simple condenser, the negative holder with moveable rods by an ordinary, ledged, negative holder, and the amplifying objective by the ordinary double lens: apart from this, everything remains the same as to the way of using it, setting it up, &c.

Fig. 4, pl. II., shows the dyalitic solar camera in section. The large condenser, A^1 B^1, is fixed at the front end, *its more convex face being turned outwards.* The correcting lens, C^1 D^1, is placed in the middle, its convex side being turned towards the objective M. The wooden frame, H^1 I^1, is moveable along the length of the camera. It is moved by a rack movement, G^1, and fixed by a screw which is at the side of the milled head working the rack, G^1. Lastly, the objective, M^1, is also placed on a piece of wood moveable in the same direction, and capable of being fixed in the same manner. The apparatus is indeed so simple that it is at once understood by inspecting the figure. We have only to say that if the moveable frames work a little too stiffly, it is only necessary to move out a little one of the thick pieces of wood between which they slide. These pieces of wood are fixed by means of screws to the bottom of the solar camera, but are nevertheless easily moveable the diameter of the screws being less than that of the holes which give passage to them.

It is indispensable that all the spherical surfaces which form, to the number of 12, the optical system, have a common axis. This is the business of the maker; but if this work, in itself

very long and difficult, were not done with the care and attention which it merits, great difficulty would be caused in printing the magnified image with sharpness and without double lines appearing on all its outlines.

The box, $O^1 P^1 Q^1 R^1$, which forms the solar camera, is usually closed at the sides by wooden doors, but we have found it more convenient to do away with these doors on the side of the handle L (fig. 5). Thus, if this handle is on the right of the circular opening which gives passage to the solar rays, then do away with the doors to the right of the apparatus. This arrangement is more convenient because with it the interior of the solar camera can always be seen, which oherwise can only be done by opening the doors, and this is troublesome.

In order to prevent light passing through these open doors into the dark room, and especially in order not to fatigue the eyes, we replace these doors by *green glasses*, which slide between two grooves, M N, O P (fig. 11, pl. II.), placed parallel to the length of the solar camera above and below. (Green, as we know, does not affect chloride-of-silver paper.)

To the end $P^1 Q^1$ (fig. 4) of the solar camera we have attached a board, Q R (*vide* fig. 11), having at its central part a hole, X, 16 centimètres square. Two small-grooved pieces of wood are placed horizontally above and below this opening. This opening can be closed by a green glass, Z, and a ground-glass, Y, of the same size. The green glass slides to the left, the ground-glass to the right. Further, the board can be moved, as a whole, up and down between two vertical grooves, S T, U V, by means of a cord, *a*, which passes over a pulley fixed to the ceiling, and the end of which is brought near the adjustible mirror, within reach of the operator who is managing it. Its object is to prevent the light which illuminates the interior of the solar camera from reaching the enlarged proof through the intervals which exist between the objective-holder and the sides of the solar camera. This frame, R Q (fig. 11, pl. II.), must be capable of being raised and lowered

in order that the rack movements may be got at. The green glass, Z, is of very great use in arresting the photogenic power of the solar light, in such a way that the image of the negative may be visible to the eye without being active on the sensitised paper, the utility of which will be better comprehended presently. Lastly, the ground-glass serves to throw a white and diffused light on the enlarged proof already printed, while it arrests the image of the negative on its ground surface.

Every apparatus ought to receive this addition, the great utility of which we have recognised in practice. We have also caused to be added to the frame carrying the objective an iron plate having a circular aperture exactly the size of the objective. This is in order to prevent the summit of the cone of rays setting fire to this board when it is displaced from the axis of the apparatus.*

Setting up of the Solar Camera.—Fig. 4, pl. II., exhibits the solar camera placed on a stand opposite the adjustible mirror. The distance between them ought to be 20 centimètres, *the interval being covered up by a black curtain*, except on the side of the handle. The knob, P (fig. 5), commanding the endless screw, T U, is, moreover, always brought to the side of the handle, L, an arrangement always practicable.

The solar camera ought to be placed horizontally on its stand, as ascertained by means of a spirit-level, S′, placed on its top; and it is necessary to take the greatest care to have the centre of the aperture, K C, of the adjustible mirror, and the centre of the condenser, $A^1 B^1$, on the same horizontal axis. *This is at once seen when, the apparatus being horizontal, the solar rays are reflected on to the front lens. This should be completely covered, at the same time that the apex, a, of the cone of solar rays emergent from the condenser passes through the objective.*

* We look upon these improvements as so essential that we have given orders to the manufacturers of our apparatus to do away from this day forward with the side doors, and to add the different pieces of which we have just spoken, leaving to those who get the apparatus the care of procuring the green glasses, the carriage of which without breakage would be difficult.

The stand of the apparatus ought to be very simple and very solid, as it is seen in the figure on page 199. Reject without any hesitation the use of stands capable of being raised or lowered by rack movements, as deficient in the stability necessary for an enlargement apparatus. At the utmost put four strong iron screws on the bottom of the stand to steady it, but still nine times out of ten the adjustment of the apparatus can be made by a good carpenter without these screws, and this is better. Besides, the stand being *firmly fixed on the ground*, and terminated at its upper part by a table having exactly the size of the bottom of the solar camera, the latter can always receive the slight displacement necessary for its final adjustment: and it is then to be fixed to the stand.

The Negative-Holder.—The support for the negatives (fig. 12, pl. II.) is formed of a wooden or metal frame, A B C D, which fits exactly into the moveable case, $H^1 I^1$ (fig. 4, pl. II.), and from which it can be readily taken out. Four grooves are made in the frame, in which four clamps, bevelled off at their lower end and which serve to hold the negative, slide with facility. If they do not, the grooves should be enlarged with a file. The clamps can be fixed by pressure-screws, shown in the figure.

The upper clamp, G, having a small pin at its lower end against which rests the metallic spring *i m*, is always pressed downwards. The spring, *i m*, is very weak, and just strong enough to keep the negative motionless when the frame is taken out, the two side-clamps being open. This spring can also act on negatives of different sizes by means of a pressure-screw fixed at its insertion, *i*. When the screw is loosened, which sets the spring free, the negative is then placed between the two clamps, H and G; the lower one, H, only being fixed. The spring is then pressed by the finger, while the pressure-screw, *i*, is tightened. The spring thus acts on the pin, G, and causes it to press against the negative. The consequence of this is, that if the heat expands the negative, this pushes up the pin; so that if the latter were fixed *the negative would break in*

pieces. The great point, therefore, for avoiding the fracture of the negatives under the influence of the great heat of the cone of concentrated solar rays, is not to press upon it by any other means than by the action of a spring.

As to the two side-clamps, we scarcely ever use them. Still they may serve to keep the negative in the plane of the frame. But these clamps must not be fixed firmly by tightening too much the pressure-screws which govern them; and, above all, they must never be allowed to bear too hard against the negative.

The spring, *i m*, might be done away with, and replaced advantageously by a leaden weight of 200 grammes, fastened at G to the upper clamp, which in this way would bear sufficiently upon the negative to keep it fixed. M. Damry, of Liége, employs this method, and never breaks a negative.

The negatives which are to be inserted between the clamps of the negative-holder ought previously to be cut with a good diamond,* and *accurately limited* to the part to be enlarged, by cutting away all those parts which are not to appear in the enlarged proof.

The best enlargements are made from negatives of *carte-de-visite* size (*vide* p. 193). If you want a full-length figure, then make the negative of *carte-de-visite* size; if you want a half-length figure life-size, take your negative on a half-plate, so that the half figure occupies a space on it a little smaller than a *carte-de-visite*—just like the vignetted busts that are made of *card* size—and cut away all the rest.

Description of the Proof-Frame.—The frame for the proofs ought to be constructed of such dimensions as that it corresponds to the sizes of the sheets usually made. That which we have used for the last four years is exceedingly

* If the edge of the negative is not cleanly cut with the diamond, a crack is often formed, though invisible to the eye, which, by extending under the influence of the heat of the solar rays, brings about the destruction of the negative.

simple, and allows of being made to suit three sizes, namely—

The photographic sheet	45 by 59	centimètres.
The double sheet	59 by 90	„
The double elephant size	80 by 105	„

We stretch these sheets on boards a centimètre thick, having the following dimensions:—

50 by 60 centimètres.
60 by 95 „
85 by 110 „

Plate II. (figs. 6, 7, and 8) exhibits the frame * completely mounted. A^2 B^2, C^2 D^2, are the two uprights of wood connected by the cross-pieces, as shown in the figure. A frame, F^2 G^2 H^2 I^2, is attached to the two uprights, presenting two ledges, F^2 G^2 and J^2 M^2 (see also fig. 8), one centimètre deep: (the same arrangement is presented at the lower part of the frame). Between these ledges are introduced the boards, 85 by 110 centimètres and 95 by 60 centimètres. There are two slots, I^2 V^2, on its vertical sides, K^2 J^2, M^2 L^2, which give passage to the screws V^2 and X^2, by means of which it is fixed to the uprights. The frame can therefore be raised or lowered to the extent of some centimètres, so that it is easy to make the height of the middle of this frame from the floor correspond *exactly* with that of the objective of the solar camera. This should be done once for all.

The breadth, G^2 F^2, of the frame being greater than that of the boards, these can slide a little to the right or left, which is necessary in order to accurately adjust the sensitive paper. This adjustment being made, the board is *solidly* fixed by small brass or wooden screws. Lastly, into the lower ledges, J^2 M^2, L^2 K^2, a board, O^2 N^2, is introduced, 95 by 60 centimètres externally, but having a ledged aperture, P^2 Q^2 R^2,

* This frame is represented in these figures one-twentieth of its size.

S^3, and receiving in its turn the boards of sheet size (50 by 60 cent.)

The light wooden boards which receive the sensitised paper are 14 millimètres thick, but are bevelled off at top and bottom so as to be only 1 centimètre thick, which is the thickness of the ledge of the frame. This bevelling permits the wedges which serve to fix the board to hold it firmly.

The board, of the size 50 by 60 centimètres, is formed entirely of wood, but the two others, of 60 by 95 and of 85 by 110, are formed of a light wooden frame fastened on a cross, and the whole covered by a sheet of brown paper, which is glued on while wet in order that it may become tense on drying (fig. 7, pl. II.)

The frame ought to be accompanied by boards on which sheets of white paper are stretched, which serve for the focussing of the image.

There ought to be twelve boards of the size 50 by 60 centimètres, six of the size 60 by 95 cent., and six of the size 85 by 110 cent., kept in a grooved box of white wood, with a thin coating of black paint outside.

If it is wished to make sizes still larger than 60 by 95 cent., the frame is turned round the other way, and a very large drawing-board is attached to the two uprights, on which the paper is stretched, as will be afterwards explained.

The sensitised papers,* either albumenised or prepared with nitroglucose, *after they are thoroughly dry*, are stretched over the frames and fastened with drawing-pins. It is not necessary to attach importance to the folds which remain in the paper, particularly in the case of portraits, or to take minute care to avoid them. We content ourselves usually with attaching the paper by ten drawing-pins, three above, three below, and two at each side. The paper is first fastened at the top, then *gently* stretched and fixed at the bottom by drawing-pins.

* We do not treat in this work of the preparation of the papers, which is identical with that of the papers which are used for ordinary proofs.

Then the sides are fixed. This operation hardly takes a minute. The boards covered with their sensitised paper are put into the grooved box, by which means they can be easily conveyed from place to place.

If it is wished to make use of only one board, for example, in the case of the very large sizes, the image is first brought to a focus on the large board of which we have spoken. Then the cone of solar light emerging from the objective is intercepted by sliding across it the *green-glass;* and lastly, illumined by this green light, which has no action on the sensitive paper while it renders the image visible on the board, the paper is fixed in its proper place.

Setting-up of the Proof Frame.—The frame for the proofs ought to move exactly in the direction of the length of the solar camera on two pieces of wood or iron. It is indispensable that the geometrical centre of the frame is situated in the prolongation of the optical axis, V*a* (figs. 4 and 5), of the solar camera. Then place under the castors, Z^2, on which the frame rests, two flat pieces of wood, or better still, have two grooves hollowed out of the floor exactly parallel with the length of the solar camera, in which the castors will run. A screw, Y^2, placed in front of the frame, enables it to be fixed in its place. To do this it is sufficient for the screw merely to touch the floor.

It is almost needless to add that it is necessary in this setting up of the frame to take care that the plane, *c b* (fig. 8), of the boards is perpendicular to the direction of the grooves, and quite vertical.

CHAPTER VII.

THE MANAGEMENT OF THE ENLARGING APPARATUS.

ALL being arranged as we have said—the lenses and the mirror well cleaned with alcohol and a dry cloth, dust removed, &c., everything, in a word, being ready for use—the instrument is worked as follows. Merely for the sake of clearness, we shall still divide this description according to the several pieces which form the apparatus.

Management of the Adjustible Mirror—(figs. 4, 5, and 6, pl. II.)—Since the rays of the sun strike full on the adjustible mirror, it is necessary to cause them to be reflected along *r r* upon the condenser A^1 B^1, and to cross exactly at the centre, *a*, of the objective M^1. This is very easily accomplished by successively turning the handle, L, and the knob, P, which govern the movements of the mirror. An assistant, remaining constantly by the adjustible mirror, ought to keep the rays reflected in this direction. There are two ways of doing this: the one by never removing the eye from the lens, $x\ x'$, of the objective which faces the negative, and on the margins of which no red light ought ever to be seen (*vide* pp. 179, *et seqq.*); the other—much more practicable and, above all, much more exact—is the following:—

The cone *b a* C, emergent from the enlarging lens, forms on the frame a luminous disc bordered by a red circle, *b e f* (fig. 6). Make sure, by looking at the lens *a*, that the image of the sun is quite in the centre, and then at once place in the red circle three drawing-pins, *g*, *f*, *e*.

The operator at the adjustible mirror keeps the red circle always on *these three* drawing-pins, by communicating a

motion to the handle and knob every twenty seconds, and it is on the precision with which he guides the mirror to attain this end that the fineness of the image in great part depends. This, however, *ought only to be done after the focussing of the image.*

When the operation is finished a rapid movement must be communicated to the handle L *in the opposite direction to that of the course of the sun*, in order to withdraw the sun's rays from the apparatus. Or else, if the enlargement of other negatives has to be continued, the green glass is slid between the enlarging lens and the magnified image, the board which bears the printed proof removed, the green glass opened again, &c., while the operator continues guiding his mirror.

Adjustment of the Negative.—Place firstly the cut negative between the clamps of the negative holder, as has been mentioned at p. 208. To do this the negative-holder ought not to be removed from its frame. First open the green glasses which close the apparatus, place the negative *reversed* between the upper and lower clamps, *the layer of collodion being towards the enlarging lens*, and then move the frame into the cone of solar rays, using for this purpose the knob G' (fig. 4), which acts upon the rack fixed on the floor of the apparatus. Cause the negative holder to move *in such a way that the red margin of the disc of light that you see on the negative by looking at it from behind falls nearly on the edges* H^1 *and* I^1 (fig. 4), *of the negative, but in all cases positively touches its angles.* For the more light there is external to the negative, the more time the enlargement will take. This is precisely why you should cut away from the negative all which need not be in the enlarged proof; and it is a matter of the greatest importance. Without this your enlargements would take much more time than is necessary.

The negative then being in position, you make the screw which fixes the rack, the wedges, &c., all quite tight, *so that nothing may get displaced should a vehicle pass:* for otherwise all the outlines will be *doubled* in the proof. The same recom-

mendation holds good for the objective and for the frame which carries the enlarged proof.

We shall speak presently of the focussing. But let us mention now, that after the focussing it is always necessary to return to the negative in order to place it quite in the middle of the cone of solar rays, and so that the vertical lines in it fall quite parallel to the edge of the sensitised paper; or else, when the proof is finished, it will be necessary to remove a not inconsiderable part of it with the scissors. This, however, is very easily done, the negative being very readily moved between the upper and lower clamps. This done, the two lateral clamps may then, but not before, be made to lightly touch the negative.

Adjustment of the Lens and the Frame.—Focussing the enlarged Image.—If the negative is of *carte-de-visite* size, the lens which accompanies the dyalitic apparatus will be suitable for its enlargement.* (See our remarks on this subject at p. 193.)

If the size of the sensitised paper which is to hold the enlarged image of the negative is 45 centimètres by 59, slide the frame 1 mètre from the lens, and double and treble that distance for sheets of double or treble that size.

Focus the enlarged image by approaching or withdrawing the lens from the negative, choosing for this purpose what seems to be the sharpest part of the negative. If the enlarged image is seen to be larger than the size of the paper, approach the frame to the solar camera, and if it is too small withdraw the frame, regulating the focus anew with the objective, and repeat these operations until the perfectly sharp image is of the size of the paper; then make the frame fast by the screw Y^2 (fig. 8). The red circle surrounding the cone of light will then fall near the margins of the paper, and under

* In our apparatus with a condenser of from 8 to 14 inches in diameter there is only one amplifying objective, suited for enlarging negatives of *carte-de-visite* size. That with a condenser of 19 inches possesses a second objective which can be used to enlarge smaller negatives.

these conditions the printing of the image on the sensitised paper will be very rapid.

A point of great importance is so to regulate the position of the lens as that the red circle surrounding the solar cone in the apparatus never falls on the edges, x' and x, of the mounting of the lens M^1,* or else (*vide* p. 178) there will be blurs of diffraction. As to the diaphragm carried by the objective, see what we remarked at p. 195.

Everything being thus arranged, close up the green glasses of the apparatus; slide the green glass between the enlarging lens and the magnified image; substitute the sensitised paper for the white screen on which you have focussed; take away the green glass, and allow the light to act. By sliding the ground-glass between the objective and the enlarged image every five minutes, you can watch the progress of the image and arrest it at the desired moment, which is identical with that in the printing of a positive on paper from an ordinary negative. Then interpose the green glass, take away the sensitised paper, &c. Do not forget to see that the assistant always guides the mirror so that the red circle keeps its place on the drawing-pins fixed on the frame.

* If this occurred it would be necessary to slide the objective backwards (away from the enlarged image) until the red is just included within the surface of the lens x', x, focussing with the negative itself, which we should be obliged to displace. But this never happens when the negative is of the *carte-de-visite* size.

CHAPTER VIII.

THE SETTING UP OF THE ENLARGING APPARATUS IN WINTER.

Alterations to be made in the setting up of the pieces constituting the Apparatus.—In our northern climates the length of the reflector of the adjustible mirror ought to be at least 50 times the diameter of the condenser, in order to reflect the rays of the sun on the 31st of December over all the surface of the condenser. With the length which we have given to it, from the end of September (and up to March) the condenser is not all covered by the reflected rays of the sun; and accordingly, instead of a round disc being seen on the proof frame, there is only a rectangle cut by arcs of a circle, while the sides of this rectangle, vertical at noon, are inclined morning and evening. Hence the necessity of adopting in winter a special arrangement, and nevertheless a very easy one, if we confine ourselves to enlargements not exceeding the size of the photographic sheet or double sheet.*

It is extremely easy to adapt to the winter arrangement all the pieces of the apparatus which we have already described, and represented in pl. II. Plate III. shows, on the same scale of 5 centimètres to the mètre, the arrangement of the apparatus in winter.

Begin by inclining the adjustible mirror forward as represented in the plate, and in such a way that two triangular pieces of wood, having *exactly* the dimensions indicated in the figure, hermetically close the openings at the side. The upper part of the mirror is fixed by a strong piece of iron, and closed up with a black cloth. On the foot which served to support the

* The adaptation of the heliostat to the apparatus allows of our working in winter *the same as* in summer. (See the ensuing chapters.)

apparatus a second one is to be placed, of the dimensions represented in the figure * (multiplied by 20), and the object of which is to bring the axis of the apparatus into the axis of the circular aperture of the adjustible mirror. Lastly, the proof-frame itself has also to be modified by adding to it two wooden tubes, A D, B C (fig. 3, pl. III.), about its uprights, which can be raised and lowered at pleasure, and be fixed by a screw, N. The proof-board holders, represented by A B C D, is fixed on the inclined cross-bar F G, so that the frame in plate III. differs from that in plate II. only by the piece F E N G, the dimensions of which must be closely adhered to,particularly thoser elating to the *inclination*. The management of the apparatus is identical with that of the horizontal apparatus, except that the frame has not only to be shifted backwards or forwards to focus the image, but more than that, the wooden tubes must be raised or lowered in order to bring the centre of the proof-boards into the optical axis.

CHAPTER IX.

SETTING UP OF THE MOVEABLE DYALITIC APPARATUS.

Description of the Apparatus.—A single inspection of fig. 1, pl. III., will enable the reader to understand the working of the apparatus.

* $\pi\phi\psi$ is a rightangled triangle in which $\pi\psi$ = 1·64 metres, $\pi\phi$ = 1·74 metres, $\phi\psi$ = 0·57 metres; which is first to be drawn on the wall, and to which the supplementary foot is to be applied in order to see if it really *has the desired* inclination.

The adjustible mirror, A B D, is fixed by means of strong cross-bars to the solar camera proper, in continuation of which is a bellows-arrangement, E F, and a wooden cone, F G, terminated by a dark-frame, G H, of which the back is white, and which can be removed from the cone. A groove, in which a Bristol-board works, permits of the sensitised paper being withdrawn from the action of the light when it is in the frame. By means of a handle, L, the bellows can be drawn out or shortened; and the whole apparatus is borne on a foot. The other pieces are identical with those we have already described.

Management of the Apparatus.—First set the apparatus * in such a way that the rays of the sun falling on the adjustible mirror are reflected into the enlarging lens, K, and to do this you will naturally make use of the guiding screws attached to the adjustible mirror. Move the negative-holder, J, into its proper place (*vide* p. 214); adjust the lens, K (*vide* p. 215) by lengthening or shortening the cone, E G (the doors of which being open permit of the enlarged image being seen projected on the white ground of the frame G H); then, when the focussing is completed, slide the green-glasses over the apparatus (not represented in the figure); close also the door of the cone, F G H; keep the direction of the reflected solar rays constant by continually looking at the objective, K; and remove the frame, G H, into which you put the sensitised paper.

To do this, open the dark frame like a book; pass a very slightly damp sponge over the back of the sensitised sheet; lay it on the bottom of the dark-frame, and allow it to dry, which

* By placing the apparatus in the open air, the mirror is always long enough, even on the 31st of December, to completely cover the condenser with solar rays, which is not the case with the immoveable apparatus (*vide* p. 217). For this purpose, it is enough for the apparatus to make a more or less wide angle with the vertical plane passing through the sun at the time of operating. When the proof is finished, the apparatus is set aside so as to *preserve this angle.*

will occupy only a few minutes. Then introduce the Bristol board by which the sensitised paper is withdrawn from the action of the light, and place the dark-frame in the apparatus.

It is necessary to have several frames, in order not to lose time; for the paper ought to be dry, so as to be tense like the head of a drum (although folds do not sensibly distort the image).

CHAPTER X.

APPLICATION OF THE HELIOSTAT TO ENLARGING APPARATUS.

THE necessity which exists of continually moving the governing screws of the adjustible mirror in order to keep the reflected solar rays in a constant direction, has made many persons seek for some means of performing this operation by means of clock-work. But to effect this the axes of the several parts of the adjustible mirror must turn with a determinate velocity, and occupy positions assigned to them by the laws which regulate the motion of the earth about its axis. Such instruments bear the name of *heliostats*. An accurate knowledge of astronomy and mechanics is indispensable to any one who wishes to use heliostats; for without such a knowledge no one can succeed in setting them correctly, and making them work with the precision of which they are capable.

Three forms of heliostats* are suitable for photographic enlargements; and all three have their advantages and their imperfections, which we shall point out in describing them.

* The other forms do not carry mirrors of large size.

August's Heliostat.—Imagine a mirror mounted in the way seen in fig. 2, pl. II., with its axis, G H, passing through the plane of its reflecting surface, and exactly coincident with the earth's axis, and turning about this axis with a velocity equal to half the sun's angular velocity round the earth—that is, making a complete revolution in forty-eight hours—and you have August's heliostat, which is necessarily of very great accuracy because of its simplicity.

The sun being in the plane of the equator, a plane perpendicular to the axis of rotation of the mirror (as on the 21st of March) at any hour of the day, it is possible to give the mirror such a position as that the reflected pencil may be horizontal, and in the plane of the prime vertical, a position which the reflected pencil will preserve all day long.

But the day following, the sun having approached the pole by a quantity δ, the reflected pencil if made horizontal will lie in a different plane from that of the prime vertical, or if taken in this plane will make an angle with the horizon equal to δ. The apparatus for enlargement has therefore to be moved every day, and this is very inconvenient. Moreover, the length of the mirror, inconsiderable in the morning if the reflected ray is towards the east, will be too short after two or three o'clock in the afternoon.

This heliostat, then, can only be practically useful in the hands of an experienced astronomer, and in a country where the sun mounts high enough in the heavens to enable us to be content to make use of the apparatus for a part of the day only.

The Heliostat of M. Léon Foucault.*—Let us leave the inventor to describe the instrument himself:—" What is a heliostat? It is a reflector which moves by itself (see the figure). In it the mirror, which is not less than 80 centimètres by 40, is attached to a mechanism which has to move it slowly all day long in such a way as to make allowance for

* *Bull. Soc. Franç. Phot.* 1862, p. 287.

the apparent motion of the sun, and reflect the light received from it in an unvarying direction.

"The sun, as you know, follows a path which varies incessantly in different countries and at different periods of the

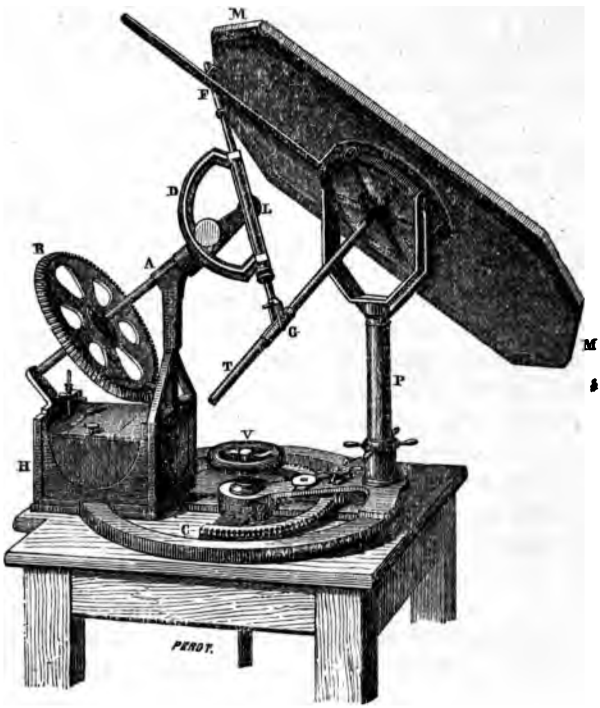


Fig. 84.

year. A perfect heliostat ought strictly, like that which we owe to M. Silbermann, to meet all the contingencies of the problem; it ought to work in all latitudes and in all seasons, and to send the reflected rays in any direction whatever at the will of the operator. I have not thought it necessary to treat the question in a manner so general. I have taken for granted that this machine set up as a fixture would never make

part of a travelling stock; and have left out of consideration the complication of varying latitudes. I have likewise supposed that in your experiments the bundle of solar rays would preserve a nearly horizontal direction; and have limited its available inclination to the small extent which is fully sufficient for the necessities of the centering and adjustment of the optical apparatus.

"Thus reduced to its essential elements, the apparatus is formed of the following parts:—

A mirror, M (*vide* fig. 84), free to move in all directions about its centre, and solidly borne on a vertical column, P;

"A clock, H, regulated by the escapement and the pendulum of the metronome;

"A horary, A, parallelly inclined to the earth's axis;

"And a guiding-rod, F G, mounted on an arc of declination, D, and attached by a moveable joint to the rod perpendicular to the mirror.

"The first thing in placing the heliostat is to make the table horizontal by the aid of a spirit-level, and to turn it round so as to place the horary axis *very nearly* in the plane of the meridian—that is, in the vertical plane through the sun at noon. Then the day of the month is to be looked for on the declination arc, and brought round and fixed opposite to the index; and the dial, R, set *very nearly* to the time. In this approximate position a line of solar light is seen passing through the sight fixed on the diameter of the declination-arc, and forming an image on the opposite plate on which two engraved lines cross each other at a right angle. To give the heliostat its exact position, nothing remains but to bring the image on the point where the lines cross; for this purpose the movement of the entire instrument on its central pivot is combined with that of the sundial. Lastly, the clock is set going, and the catch is pressed down which puts the dial in train with the wheelwork. The instrument is known to be well placed by the small image continuing to rest on the point of crossing of the lines.

"If now it is wished to cast its light in a determinate direction, the pinion which moves the column P is turned, and the reflected rays are made to follow the direction of the line which passes through the centre of motion of the mirror and the middle, L, of the guiding rod.

"It is easy to understand why the mirror has an elongated form. It is always necessary in order to send the sun's rays horizontally into our houses to incline the mirror more or less, which considerably foreshortens its reflecting surface; and for this, allowance has to be made in the length of the mirror. Besides having this elongated form, the mirror must be able to set itself in the plane of reflection; and it is for this reason that it turns on agate planes, and that it is attached to the guiding-rod by a groove fixed parallel to the back of the frame.

"All these conditions which it was necessary to fulfil have been perfectly included by M. Dubosq. This large machine works with the accuracy of a mathematical instrument. In its execution M. Dubosq has found occasion to introduce into it the improvement of a spring concealed in the column of the mirror which assists it in surmounting difficulties which do not occur in practice, but which would not have failed to give occasion for adverse criticism. This is an improvement which I thoroughly appreciate, and which would give a high conception of the practical sense of the maker had we not many times already had opportunity of forming in this respect a very decided opinion."

The heliostat of M. Foucault works with great accuracy if the direction of the reflected rays is from the south to the north or differs little from it. Otherwise the least irregularity in the clock's movement or in the setting of the instrument in position may give rise to great disturbance in the direction of the reflected rays. But it is always easy to place the apparatus nearly in the direction of the meridian.

In winter the mirror of M. Foucault's heliostat is much too short to fully cover a lens 14 inches in diameter with reflected

rays; and it is only from April 1st to September 1st that this can be done.

Finally, if the process lasts some time, the image of the sun at the focus of the condenser is apt to get *slowly* displaced, and there is no provision for readjusting the mirror by which to correct the position of this image while the heliostat is in action; consequently, the process has to be interrupted. To render the instrument thoroughly efficient, it would be necessary to adapt to the axis and to the declination-arc two adjusting screws, by means of which the error might be corrected without having to stop the clock-work.

Fahrenheit's Heliostat, modified by M. V. Monckhoven.—This heliostat has the advantage over that of M. Foucault of being far simpler, and of thereby having a much more regular motion. Further, it can be as well made use of on December 21st, the time at which the sun is at its lowest, as on June 21st, when the sun is at its highest, and this in any part of the world. On the other hand, it is requisite that the optical apparatus be placed in the plane of the meridian, and inclined to the horizon at an angle equal to the latitude of the place; and to do this is often both inconvenient and difficult, though when once accomplished, it always remains so.

For the rest, the following is a full description of all the parts which form the heliostat. The table N (fig. 85), is of turned and polished iron. It is supported on three screws, one of which is seen at O, and presents at its centre a conical part, about which turns the piece L M, capable of being made fast to it by tightening the screw *a*. To render the table horizontal, a good spirit-level, 15 cent. long, is applied to its upper surface, in the direction of two of the screws, and one of them turned until the air-bubble comes to the middle. The spirit-level is then turned round, at right angles to its first position (the position of the piece, L M, being shifted for this purpose), and by means of the third screw, the air-bubble again brought to the middle. The table is then horizontal.

Frequently the screws, on which the table rests, are suppressed, and the piece, L M, fixed to the table, N—the heliostat in this case being mounted on one foot with the optical enlarging apparatus. Then, the spirit-level must be

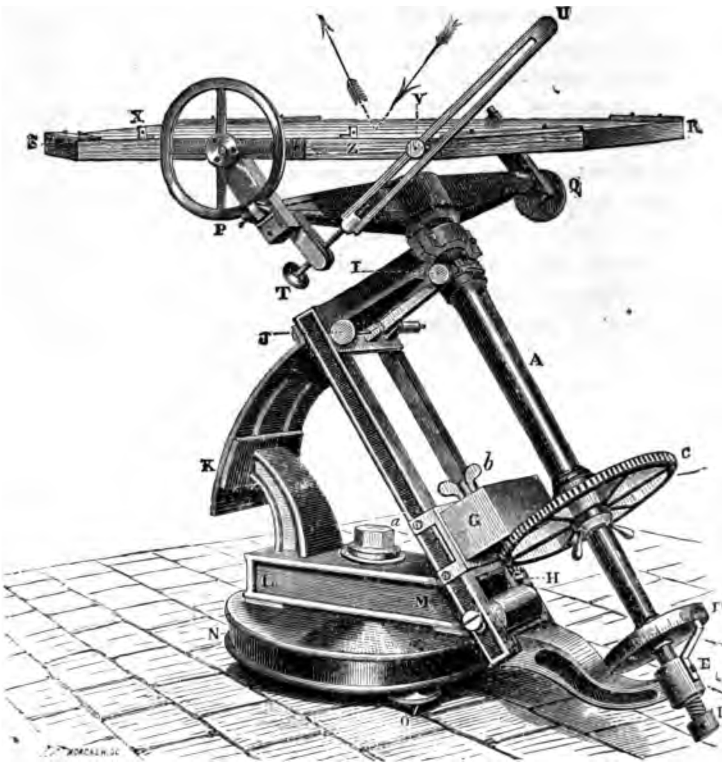


Fig. 85.

placed on the table alongside the piece, L M, and the table rendered horizontal by means of the screws attached under the foot of the entire apparatus.

The support, J K L M, is of iron. The arc, J K, necessary

for the adjustment *for latitude*, is moveable, but is fixed by the maker to the latitude for which the instrument is required. No attempt, therefore, must ever be made to move this arc, J K; on the contrary, it must be preserved from all displacement.*

To the piece, J K L M, is fixed the arm-rest in which the axis, A, turns, as the figure sufficiently explains.

The *axis*, A, is of steel, fixed by a screw to the arm-rest, P Q, and rests upon the brass screw, B, which serves to bring the several pieces into position. The screw, B, is made fast by a side-screw. The parts of the axis touching the bearings must be kept always well oiled.

The *toothed circle*, C, is fastened to the axis by a screw, of which the thread runs the reverse way, in order that it may not get loose by the rotatory movement of the axis. This screw also should be securely fastened. The wheel, C, is divided into 360 teeth, and *must be kept clean* by means of a brush passed over it every day in the direction of the length of its teeth.

The *horary circle*, D, divided into hours from six in the morning to six in the evening, then into parts of twenty minutes each, and lastly, into others of four minutes each, is fixed on the axis by an hexagonal nut which can be tightened by the hand. The index, E, slightly moveable, serves to indicate the time on the horary circle, and has, for this object, a line engraved with a diamond on its upper part.

The *collar*, I, works in a groove cut in the axis, A, and can be made one piece with the axis by tightening the screw I, or be left to turn freely about the axis by loosening the screw I, which must be handled gently and never screwed up very tight. This collar terminates at its lower part in a rod, constantly pressed towards the letter J by a spiral spring.

* It is easy to verify if the axis, A, is inclined to the table (previously rendered horizontal) at an angle equal to that of the latitude of the place. For it to be so, the mirror, S R, being placed horizontal, the index, P, ought to point to 90°—*l*.

A screw, J, therefore, fixed on an arm-rest, which is attached to the immoveable part of the heliostat and which also carries the spiral spring, enables the collar to be moved in one direction or the other (and consequently the axis, A, if the screw I is fast) by very small degrees at a time. After having used this part of the apparatus frequently, the rod which works between the adjusting screw and the spring may get caught against one of the two brass supports which carry them. The screw J must then be turned until the rod reaches the middle, and the axis, A, turned with the hand. The rod is brought exactly into the direction of the screw J and the spring by the screw B. But this is always done by the maker.

The *arm-rest*, P Q, is of iron. At one end it carries a counterpoise, Q, which serves to balance it about the axis, A; and at the other an index, P, and an adjusting screw, T U, of which we shall speak presently.

The *mirror*, S R, is octagonal, of finely silvered glass. It is mounted in a frame of polished ebony, and has at its two extremities two pivots of polished brass of exactly the same diameter, and with their imaginary axis passing through the reflecting surface of the mirror, and at right angles to the index X Z and to the axis A. These pivots revolve on the arm-rest P Q on Y-shaped bearings, and are kept in place by plates of brass.

The *declination-circle*, P, is fixed on one of the pivots and divided into half degrees. When the zero of the graduation is brought opposite the index, the surface of the mirror is exactly perpendicular to the axis A*—an adjustment made

* This adjustment is made thus (fig. 2, pl. IV.):—The zero of the circle having been brought opposite the index—which is easily done with the adjusting screw T—and the screw V being fast (fig. 85), place the point of a needle D (fig. 2, pl. IV.) in such a way that it touches the lower part of the mirror. Then turn the mirror, B C, gently round its axis A, so *that* the part B may come round to the needle, which ought still *to touch the mirror*. If it does not, correct half the difference by shifting the needle

by the maker, and which must never be deranged in dismounting or shifting the index. In the position of the circle shown in fig. 85, the circle must be read to the right of the zero (fig. 1, plate IV.), in *winter* (from September 21st to March 21st), and to the left of the zero in *summer* (from March 21st to September 21st).

The *index* (fig. 1, pl. IV.) is formed of a moveable plate of brass, which can be applied to the division of the circle, or removed from it by pressing on the lower part. A single line traced on its upper surface serves to indicate the division of the declination-circle; and as the half and even the quarter of each of them, corresponding to $\frac{1}{4}$ or $\frac{1}{8}$ of a degree (15 or $7\frac{1}{2}$ minutes of an arc) can be very well estimated, this amply suffices for the adjustment of the instrument. It is necessary, however, to be well practised in reading the circle, or better still, to get assistance from some one accustomed to this kind of readings, which besides requires to be done but once for all.

The *bar*, U T, consists of a slide-rod, capable of forming one piece with the mirror by tightening the screw V. An adjusting screw, T, attached to the arm P Q, allows, when the screw V is fast, of the mirror being moved very small distances at a time.

The two *sights*, X, Z, are squares of brass-plate, placed at the sides of the wooden mounting of the mirror, each being pierced by a small hole. Further, the sight X bears on its surface, facing the opposite sight, two lines perpendicular to each other, traced with a diamond, one being parallel to the surface of the mirror.

When the sights, X, Z, are brought in a line with the sun,

and the other half by the adjusting screw T (fig. 85), and repeat this operation until, on turning the mirror upon its axis, both its upper and its lower parts just come into contact with the point of the needle as they present to it. Then correct the index by moving it until the line which is marked on it exactly coincides with the line 0 of the graduation traced on the circle. This operation is performed with the greatest exactitude by the maker before delivering the instrument, and if the index has not been touched we may be certain of its correct position.

a thread of sunlight is seen proceeding from the aperture in the sight Z, and falling on that of the sight X, where it forms an image of the sun. *In performing this operation we are guided by the shadow of the sight Z, which ought to fall parallel to the wooden mounting of the mirror.* The hand is besides held behind the sight X, in order to bring the shadow of the other sight more easily upon the first.

The *clock-work*, G, is enclosed in a brass box, is wound up by the key *b*, goes 10 hours, and communicates its motion to the wheel C by its pinion H.

The clock-work is fixed to the immoveable part of the heliostat by four screws, but by slightly loosening the two inferior screws and lowering the clock-work, the pinion H is thrown out of gear. The pinion, H, can at pleasure be put in train with the clock-work or be rendered independent of it, by tightening or opening the nut H. If it is unscrewed, the axis, A, can be slowly turned, and then the pinion is seen to revolve rapidly. If it is screwed up, the clock-work immediately acts on the toothed-wheel, C, so as to make it perform a complete revolution in 24 hours. Care must always be taken not to lose the nut H and the pinion, which are liable, if the axis, A, is too frequently turned round, to get detached. It is accordingly well to hold the nut between the fore-finger and thumb, either to keep it open or to screw it up. Keep also the open part of the box under the key *b*, covered by a brass plate so as to prevent dust from getting into the box.

Management of the Heliostat.—Wind up the clock-work, loosen the screws V, I, H, take hold of the mirror at R, and give it its proper direction, about which we shall speak farther on; when this is *very nearly* effected, tighten the screws V and I, and adjust the mirror by the screws T and J to give it its correct position; then immediately close the nut H and loosen the screw I, and the mirror will obey the clock-work.

Setting the Heliostat.—Make the table, N, horizontal in

the way described at p. 225. Keep the screws *a*, V, I and H loose, after having wound up the clock-work.

Begin by rendering the mirror horizontal by applying the spirit-level to its surface in the direction X Z, tighten the screw V, and complete the adjustment with the screw T. Then applying the level to it in the direction of the pivots (and at right angles to X Z) tighten the screw I and complete the adjustment with the screw J. Go through the two adjustments again, without loosening the screws V and I, making use of the screws T and J only.

Having thus rendered the mirror quite horizontal, see if the line xii of the horary circle, D, is quite in juxtaposition with the line marked on the index E, and if it is not so, move the index and the circle, D, cautiously, so that these two lines become a prolongation one of the other—but without the index, E, touching the circle, D, otherwise a displacement of this index might take place in turning the axis, A. Now loosen the screws V and I.

Find out from an astronomical almanac the *declination* of the sun on the day on which you are working, and, taking the mirror in the right hand at R, communicate to it such a motion as to *very nearly* bring the indicated degree of the circle, P, opposite the index. Tighten the screw V, and turn the screw T until the index exactly marks the declination of the sun at the time.

Taking now the mirror in the hand at R, and noting on your watch the *true time** make the index indicate this time

* The *true* or *apparent time* is the time marked by the sundial, and not the time marked by the ordinary clock, which is *mean time*. The difference between the mean time and the true time constitutes the *equation of time*.

To set a heliostat well, a knowledge of the exact time (to within a minute) is indispensable, and should be carefully attended to. Throughout the United Kingdom, at all railway stations, Greenwich *mean* time is always adopted for civil convenience, although obviously that time does not truly indicate mean time in other localities situated east or west of Greenwich. In any place, therefore, where a heliostat is to be arranged for the day, it

on the circle, D, by communicating a rotatory motion to the axis A. When this is *very nearly* effected let go the mirror and tighten the screw I. Then turn the entire instrument round on its pivot, *a*—taking it by the screw B, and without stirring the table, N—*until you see the thread of solar rays emerging from the aperture of the sight* Z *and falling on the centre of the sight* X. Then tighten the screw *a* and the heliostat is set. A much easier means of setting the heliostat is pointed out farther on.

If now, *in succession*, you open the screw I and close the screw H, you will see the image of the sun remain motionless for hours together at the centre of the sight X, *and it is only when this is the case that the heliostat is accurately set.* It must never be made use of until its working has been thus

will be very easy to calculate the *true* or *apparent* time by the following data:—

1st. The exact longitude of the spot to within fifteen seconds must be accurately ascertained. This can easily be got from the Ordnance maps.

2nd. Greenwich *mean* time must be known; and this, to within a few seconds, can be ascertained at the nearest railway station.

3rd. An astronomical almanac (Dietrichsen and Hannay's is very convenient and cheap), containing the *equation of time*, *declination of the sun*, *&c.*, for every day of the year, is required.

With these data known, suppose it is wished to arrange a properly set-up heliostat at Liverpool for a day's work, say at nine o'clock on the 1st of October, 1867. The longitude of Liverpool is three degrees west of Greenwich; the *true* time at that place is, therefore, exactly twelve minutes *later* than London time. First ascertain accurately nine o'clock by Greenwich mean time, deduct from that twelve minutes for difference of west longitude, then turn to the almanac for the *equation of time* for that day, which happens to show *minus* ten minutes fourteen seconds. In other words, the sun is faster or passes the meridian sooner than the mean time indicates. This difference must therefore be added to the *mean* in order to get the true time. Thus:—9 hrs. − 12 min. + 10 min. 14 sec. = 8 hrs. 58′ 14″, which is the time at which the horary circle of the heliostat is to be set for that day at Liverpool. And so for any other place, taking care, however, to note that a divergence from Greenwich time must be *added* when the place is east longitude, and that every 15′ of longitude is equivalent to one *minute* of time.

verified. When the heliostat is set, the table N and the pieces L M, K J, J M, being left in position, all the other parts may be dismounted and taken away. To do this, open the nuts which hold the circles C and D; lower the clock-work; open the collar I, by removing the screws which close it round the axis; and open and remove the upper half of the bearing in which the upper part of the axis works. The mirror, the arm-rest, and the axis can then be removed, without the heliostat having to be reset when they are replaced.

To take out the mirror alone, the screws V and T are first taken out and then those which hold the mirror in the arm-rest P Q, the index P is turned outwards, and the mirror removed.

CHAPTER XI.

SETTING UP THE HELIOSTAT WITH THE ENLARGING APPARATUS.

Three ways of setting up the heliostat may be adopted:—

1st. The most simple consists in inclining the enlarging apparatus so that its optical axis coincides with the axis of the heliostat.

2nd. The second consists in rendering the reflected rays horizontal by means of a second mirror, and in any direction whatever.

3rd. The third in rendering the reflected solar rays horizontal by a mirror inclined at 45° to the axis of the heliostat, in such a way as to reflect them from the east to the west, or from the west to the east.

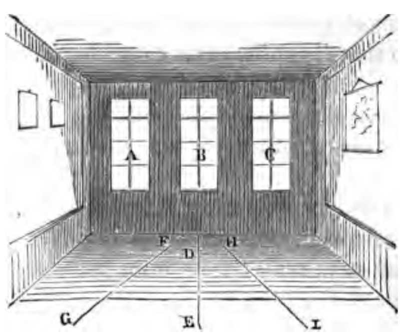
SECTION I.—*Apparatus inclined to the Horizon.*

Description of the Apparatus.—Fig. 4, pl. IV., represents this arrangement very accurately, including the wooden shed which serves to protect the instrument from the rain.

This apparatus ought to be set up in the open air on a platform or a terrace, or in a garden or a window balcony;* but in every case the floor must be made quite firm, &c. The apparatus is composed of parts quite distinct from each other.

1*st.* The *heliostat proper.* It is similar in every respect to that of which we have already given the description (pp. 225, *et seq.*), and of which fig. 85 gives a true representation, with this difference only, that the three screws of the table are suppressed; that the table is fixed immovably on the base of the foot A B (fig. 4, pl. IV.), *from which no attempt even must be made to move it* for fear of deranging its adjustment; and that the pieces L M and J K (fig. 85) are made fast—for the

* Look, at *true noon-time*, at the direction of the shadow of the vertical cross-bar of the window. If this shadow falls to the left, F G, put the apparatus to either the window B or A; if the shadow falls to the right, H I, put the apparatus either to C or B; and if the shadow is perpendicular to the wall, select the window B. But the window always ought to open on a level with the balcony outside and with the floor of the room.



maker accurately adjusts the heliostat so that its axis rigor ously coincides with the axis of the optical apparatus. To effect this adjustment the maker takes out the lenses of the apparatus, and replaces them by circular discs of metal, having at the centre a concentric aperture five centimètres across. He takes out the axis of the heliostat, and slides in its place a cylinder of wood two mètres in length. He brings in this way the axis of the heliostat and the apertures in the discs all in a line with the cylinder of wood, and this done, he makes all the parts immovable. It is therefore necessary to be careful not to derange them. Above all, do not remove the table C (fig. 85) from the foot to which it is attached, and do not derange either the piece L M or the arc J K. But you can remove the mirror, the axis A, the clockwork, &c., provided, and this is essential, the fixed part of the heliostat remains so.

2nd. The *foot*, D E C U A (fig. 4, pl. IV.), of which D E makes an angle with A B just equal to that of the latitude of the place for which the heliostat is constructed. It is necessary, once that the apparatus is put up and adjusted, to fix it firmly to the sides of the shed by lintels of wood and its part A B to the floor, in order to prevent it from oscillating or moving. Two screws, one of which is seen at C, serve to render the foot horizontal in the direction of the length of the apparatus, and in a direction at right angles to this.

The *optical apparatus*, H I, which is in everything like the apparatus represented by fig. 1, pl. III., and worked in exactly the same way (*vide* p. 219).

The shed which shelters the instrument is drawn in the figure, just *one-twentieth* * of its real size, for the apparatus of which the condenser is fourteen inches in diameter, and for a

* For the apparatus of which the condenser is only eight inches in diameter take three-fifths of the measurements which refer to the apparatus of which the condenser is fourteen inches in diameter. As for the apparatus of which the condenser is nineteen inches in diameter, it is not constructed in this way because of the height to which the building would go, and of the difficulty there would be in managing it.

latitude of 45°. But if the latitude *varies*, the height of the shed varies, as well as its length. As for its width, that remains unaltered. Here are, however, the exact numbers relating to fig. 5, pl. IV.:—

Latitude.	L V Mètres.	L K Mètres.	O P Mètres.
30°	2	2·50	3·0
40°	2	3·0	2·50
50°	2	3·25	2·25
60°	2	3·50	2·25
O M = 0·80; O S = 0·80; R M = 1·50; T U = 1.			

This shed is made of one-inch boards and is *previously* directed towards the sun, which at *true noon-time* ought not to cast a shadow on its longest sides (O P, fig. 5, pl. IV.) In front it opens, as shown in fig. 5, the two side-doors and the flap being analogous to those in fig. 9, pl. II.

The door is placed at the bottom of the side L K (fig. 4), and ought to be from 2 to 2·50 mètres high and 1 mètre across.

Setting the Apparatus.—Nothing is easier than setting the apparatus. Firstly, it is placed in a direction from south to north (the heliostat to the south), and in doing this the place of the sun at the true noon-time is the guide.

Place on the table N a *spirit-level* close to and parallel to the piece L M (fig. 85); then in front of the heliostat arrange a plumb-line formed of a string two mètres long and two millimètres thick, to which you suspend a weight (of half a kilogramme), plunged in a small bucket of water so as to render it less moveable.* Dispose the plumb-line in such a

* Fig. 6, pl. IV., represents the arrangement. A B, A C, A D, is a tripod (a pair of steps will do also), E G the plumb-line, and H the bucket. A wooden triangle, A (fig. 7, pl. IV.), attached to the optical apparatus, B, and carrying the plumb-line, a b, will also do.

way that its lower part is at a very small distance from the screw B (fig. 85) of the heliostat. Now carefully set your watch to the true time as described at p. 231, and at the *true noon-time precisely* move the entire instrument from right to left or from left to right, so that the shadow of the plumb-line divides the screw B (fig. 85), the circle D, the axis A, and the case of the optical apparatus, into two *quite equal* parts.

A second person at the screws which are found at C (fig. 4, pl. IV.) at the back of the foot, A B, turns them so that the spirit-level placed on the table N (fig. 85) against the piece L M indicates the horizontality of the table. It is necessary to commence this operation some minutes before noon, to remove the mirror X R, to operate gradually and to stop precisely at the true noon-time, beginning again the next day.

This operation, performed *with care*, is more than sufficient to set the heliostat very accurately, but the wind may often interfere with it. Always take great care that the plumb-line is as near as possible to the instrument, without, however, letting the bucket touch the foot of it. The nearer the plumb-line is, the sharper does its shadow appear.

Another way of setting the heliostat is the following, which must likewise be performed as near noon as possible.

The point xii of the horary circle being placed as has been described at p. 231, put the circle P (fig. 85) at the sun's declination, and the circle D at the true time. Then at once move the entire instrument with its foot, A B (fig. 4, pl. IV.), until you see the image of the sun form at X (fig. 85). You are to proceed as directed at p. 231, substituting the movement of the entire instrument for the movement of the single piece L M. But always keep the table horizontal by the foot-screws. The operation must besides be performed several times successively, as has been mentioned at p. 231, line 11, *et seq.;* and it must then be tried if the instrument is well set by making the clock-work act on the toothed circle C, in order to see if the sights remain constantly in the direction of the sun, in which case the image of the sun remains

motionless for hours together at the centre of the sight X (*vide* p. 232).

This done, the instrument is set once for all, and you should fix the foot to the ground by screws or load it with blocks of stone, in order to render it quite firm. It is always well to place the apparatus on a well-hardened piece of ground, on a thoroughly firm flooring, on a foundation of masonry surmounted by a large flat stone, or on something of this kind.

Management of the Apparatus.—The management of the apparatus is exactly like that of the ordinary apparatus, of which we have spoken in the instructions at p. 218, *et seq.*, and which is seen in fig. 1, pl. III. Only let us remark, if the operator desires to enlarge negatives to sizes exceeding the photographic sheet—the size which the apparatus allows of—he will throw the image on to a large board placed at the upper part of the shed in a suitable position.

Whatever may be the time and the sun's declination—which have only to be considered on the days when the apparatus is set—we commence by loosening the screws V, I, and H of the heliostat (fig. 85), and then, holding the mirror at R whilst looking at the centre of the enlarging lens, we direct the solar rays upon it. When we have brought them very nearly on to it, we tighten the screws V and I, and finish the adjustment with the screws T and J. This being effected, we tighten the nut H and loosen the screw I; and then the heliostat, obedient to the clock-work, keeps the image of the sun for hours together at the centre of the enlarging lens, provided that it has been correctly set, and that the apparatus from that moment has remained exactly in its place. But if the sun's image, getting slowly displaced, comes to touch the margin of the objective, rectify it by loosening the nut H, tightening the screw I, and touching the screws I and J. The rectification made, screw up the nut H, and loosen the screw I. All this is done in some seconds, without sensibly checking the motion of the apparatus. Of course, first of all, the clock-work has to be wound up.

When it is wished to terminate the operation, the nut H and the screws I and V are loosened, and the part, S, of the mirror brought against the arc of the circle K; then leaving all in this state, the shutters which preserve the heliostat from dust and rain are closed.

The opening in the shed which gives passage to the heliostat should be capable of being closed by easily moved curtains, which shut out the heliostat from the interior of the shed. When the reflected solar light is directed by the heliostat into the apparatus, the curtains are opened in order to see into the optical apparatus. Protect the foot of the apparatus, even the part situated under the heliostat, from the heat of the sun's rays by covering it with a cloth lined with wadding or hay.

SECTION II.—*Apparatus with the heliostat of two mirrors.*

Application of the Heliostat to apparatus with ordinary adjustible mirror.—All enlarging apparatus, both on our system and on the old system of Woodward, can have the heliostat applied to them, if in front of the adjustible mirror there is a clear space of one mètre and a half in all directions.

To thoroughly comprehend how these apparatus are placed, it is necessary to bear fully in mind the principle that the heliostat figured at p. 226 keeps the sun's rays reflected in the direction of the prolongation of the axis A. If now a second mirror is employed to reflect the rays again in any direction whatever, they will still be given off motionless, since they are first made so by the heliostat itself. There is, it is true, the loss of a tenth of the light by the employment of a second mirror, but, on the other hand, there is the advantage of dispensing with the assistant placed in charge of the ordinary adjustible mirror. This system has moreover been employed since January 1st, 1864, by M. Damry of Liége and M. Verbeke of Louvain with complete success. Their

enlarging apparatus is horizontal, and they employ the heliostat, so simple and easy to work, represented by fig. 85. The diameter of the condensers of their apparatus is nineteen inches.

In all parts of Europe, and above all in the north, this way of mounting the heliostat is very convenient, particularly if the direction of the enlarging apparatus, already set up at the time of applying the heliostat to it, instead of being from south to north, makes a considerable angle (an angle of 45°, for example), with this direction, and is rather from east to west or from west to east. A wall facing the east, the south-east, the west, or the south-west, is more favourable than a wall towards the direct south. Nevertheless, if, following the instructions which always accompany all enlarging apparatus, the setting towards the south should have been chosen, it would be well, previous to the operations for mounting the heliostat which we are abóut to indicate, to shift the apparatus from this direction, placing it across the room in line with the south-east or south-west, at the same time moving into this direction the adjustible mirror also. All this, as we shall soon see, is for the purpose of preventing the shadow of the ordinary adjustible mirror in summer time from covering any part of the mirror of the heliostat.

Operations preliminary to the Setting up the Heliostat.—Fig. 4, pl. V., gives a clear idea of the operations preliminary to mounting the heliostat. Let A be our adjustible mirror, from which the mirror itself has been removed and replaced by a rod of wood turned in a lathe, and resting on the bearings *a* and *b*, which terminate the iron arms. Suspend from the middle of this rod a plumb-line, which will touch the ground at *c*. Suspend another plumb-line, E F, a mètre or two in front of the first, and, precisely at true noon-time, move this line until its shadow, F C, passes exactly through the point C. Trace on the ground the straight line C F, which will evidently be the *direction of the meridian*. If now B F makes with C F an angle equal to the latitude of the place, it

is clear that this line *exactly* represents the axis, A, of our heliostat which has itself also to be in the plane of the meridian, making with C F an angle, F, equal to the latitude of the place.

If the height B C is from 1·50 to 2 mètres, the heliostat will then be easily applied, because there will be a sufficient distance between the heliostat and the adjustible mirror.

The preliminary operation consists therefore in setting up the plumb-lines B C and C F, so as to get the straight line C F, which represents the meridian, or north-and-south line.

Application of the Heliostat.—Now, on a packing case or temporary wooden stand, some centimètres high, mount the heliostat so that its axis, A (fig. 85), is projected along the straight line C F, and set it by means of the sun just as we have described at p. 234, *et seq.* When the heliostat is fully in position and *working*, loosen the screw V very gently, depress the part R of the mirror until the circle P just indicates the number of degrees and parts of a degree of the sun's declination as given in an astronomical almanac for the date of the day on which we operate. Then tighten the screw V, and properly adjust the circle by means of the screw T.

The sun's rays are now reflected in the direction of the axis of the heliostat, and if the instrument is set up in a proper position—that is, if the axis of the heliostat coincides with the imaginary straight line B F—all the rays reflected by the mirror of the heliostat will be seen to fall on B. To see this better, paste white paper over the entire surface of the mirror of the heliostat, excepting its centre, where you leave an open circular space five centimètres in diameter. (The centre of the mirror is the point which divides into two equal parts the straight line which joins the two pivots).

In working with a mirror thus covered up, you will see the reflected image of the sun by interposing a white card in the course of the reflected pencil in the neighbourhood of the adjustible mirror. This solar image ought to fall exactly on the point B, and if it does not do so we must try to make it

do so within some centimètres, by moving the heliostat and resetting it. Then, replace the provisional foot by a small mass of masonry of the same height resting on the ground, and bounded at top by a very smooth and quite horizontal stone surface, about one mètre square. Upon this rest your heliostat, recommence the setting, place the mirror of the adjustible mirror horizontal, reflect the already reflected solar rays into the enlarging apparatus, and see if the condenser of this apparatus is fully covered by the solar light; if this is not the case your heliostat still does not send the solar light into the apparatus properly.

There is a simple and easy means of moving your heliostat, so that its reflected rays may take a perfectly right direction.

Have a small flat wooden rule, A B (fig. 3, pl. IV.), made, fifteen centimètres long, and with a sight at each end analogous to those, X, Z (fig. 85), placed on the sides of the mirror; and fix this rule by a screw, C, to the side of the mirror. When you have lowered the mirror until the circle P just indicates the given number of degrees of declination—when, in a word, the sun's rays are reflected on to the adjustible mirror —make the rule, A B, rotate gently about its centre, C, until the solar rays, entering by the sight B, just form a round image on the sight A, the place of which you mark by a metallic point. If the heliostat is in action and is well set, the sun's image on the sight A will remain motionless, as well as that at the focus of the condenser of the enlarging apparatus. If this condenser is not fully covered by the sun's rays, it is because a part of the light reflected by the heliostat falls to one side of the adjustible mirror. You can now shift your heliostat without disturbing its setting by seeing that the sun's image, during the shifting, always falls on the same place on the sight A. You could in this way move the heliostat where you liked, on condition that the mirror is moved by the clockwork.

The heliostat once in right position, keep the adjustible *mirror* quite still, and if the reflected pencil does not remain

quite motionless, rectify it exactly in the way described at p. 238, line 30 *et seq.* But it will remain motionless if it has been set exactly to the right time, and if the declination has been carefully read off.

Once the apparatus is in position, it is protected from the rain by covering it with a small wooden case, which may be constructed according to the operator's taste.

After this, to make use of the apparatus, it suffices to direct the sun's rays into the enlarging apparatus just as we have described at p. 237.

Fig. 5 (pl. V) * represents the most favourable arrangement in setting up this apparatus when from want of the necessary space under the adjustible mirror a wooden shed is obliged to be erected on a terrace or in a garden. In this case the optical apparatus is directed along the line C D (from east to west), and the heliostat, A, is placed at a corner of the building. The length, C D, of the building is five mètres, and its breadth two, and the height, F G, of the floor from the ground one and a half mètre.

SECTION III.—*Another disposition of the Apparatus with the Heliostat of two Mirrors.*

Description of the Apparatus.—This apparatus, represented in fig. 8, pl. IV., is in the main exactly similar to the preceding, with this difference, that the second mirror, instead of being between the heliostat and the condenser, is behind the condenser itself. It is more easily set, but requires a building, if not erected expressly for it, at least adapted to it, such as a room with a window balcony, &c.†

* Only the draughtsman has wrongly placed the heliostat, A, which ought to be in front of the post I, and not behind it.

† Supposing it to be the room in fig. 86, the apparatus will be placed at the window C if the shadow of the vertical bar of the window is along H I at *true noon-time;* and at the window A if this shadow is along F G, but in this case the maker must be told to change the box K O (fig. 8, pl. IV.) to the other side, and to alter the position of the reflector from along C E to along B D.

In other respects, it exactly resembles the apparatus described at pp. 225, *et seq.*, and is set in the same way: therefore the reader, after having made himself acquainted with the detailed description of the heliostat which we have given at pp. 225, *et seq.*, ought also to study pp. 233, *et seq.*, for we shall pass rapidly over the details of the mounting of this apparatus.

The following is a description of the apparatus (fig. 8, pl. IV.):—

The heliostat is exactly like that which we have described at pp. 225, *et seq.* (fig. 85), save that the three screws of the table are in it suppressed, and also the movement of the piece M L about the screw *a* and that of the arc K J. This heliostat therefore is fixed immoveably on a cast-iron foot, Q R (fig. 8, pl. IV.), which carries at its end R two adjusting screws serving to make the table of the heliostat horizontal, just as in the apparatus described at pp. 234, *et seq.* The stand S, fixed also immoveably on the iron foot Q R, carries a cubical box, C E G, made of very thick oak. In this box is the condensing lens H, the axis of which coincides rigorously with that of the heliostat. The side of wood opposite presents a circular hole five centimètres in diameter, which also coincides with this axis, and which enables the apparatus to be very accurately adjusted. This is how the maker proceeds for this purpose. He fastens the heliostat on the cast-iron foot, renders the table quite horizontal—so made as that the axis of the heliostat forms with the table an angle *exactly* equal to the latitude of the place for which the heliostat is intended—and then fixes the pieces M L and K J (fig. 85) with strong irremovable screws. He next removes the axis A from the heliostat, replaces it by a very accurately turned cylinder of wood two mètres long, and then, removing the glass, I J, and replacing the condenser by a circular card with a hole in its centre also circular, he fixes the stand S (fig. 8, pl. IV.) on to the cast-iron foot when the two apertures (that in the card and that pierced in the opposite side) are exactly

obstructed by the wooden cylinder. The axis of the cubical box thus becomes exactly coincident with the axis of the heliostat; but for this to be perfectly so in relation to the other parts of the optical apparatus, extreme care must be taken to give it a true cubical form. *The heliostat, therefore, must never be removed from the foot* Q R, *nor any attempt be made to shift the stand* S *and the cubical box. This is of great importance.*

The negative lens U is fixed in the side E D of the cube; the negative holder, V, and the enlarging lens, X, being in a separate box, K O, of which the axis, at right angles to the axis of the heliostat, is horizontal. Before setting the apparatus, *this box*, K O, *as well as the condenser*, H, *and the glass*, I J, *must be removed*, and the condenser replaced by the card having a concentric aperture of which we have spoken above.

Setting the Apparatus.—For the rest, the apparatus is set *exactly* in the way we have given at p. 236, both by the plumb-line in the first place, and then more precisely by making use of the true time marked by the horary circle, and of the declination of the sun on the day when the apparatus is set.

When the mirror obeys the sun very accurately, keeping its image motionless on the sight X (p. 232), the adjustment of the mirror J I must be proceeded with, and, before doing so, the box K P be adjusted, after having fixed the foot Q R solidly to the ground either by loading it with blocks of stone or by screwing it to the ground with bolts.

Set the heliostat going, and reflect the sun's rays on to the card H in such a way that you see a circular line of light round the hole made in the side C D of the wooden cube. Then tighten the screws of the heliostat, and see at the end of half an hour if the sun's rays reflected through the aperture in the card keep their place well—as they will do with surprising exactness if the heliostat is well set. And, if they do not, examine well whether you have not forgotten to tighten one of the screws of the heliostat, or have badly put the clock-work in train, or done some such thing; and then

begin again the setting itself, not forgetting that quite the exact time is necessary for this object.

But when the reflected solar rays remain quite motionless on the aperture in the side C D, introduce the lens H, and cover it with the circular card which limits it to its central part. Then introduce the mirror I J, previously well cleaned, between the corner-pieces which serve to keep it in the diagonal of the cube, and see if the round image of the aperture H is cast exactly on the middle of the enlarging lens—without, of course, at any time stopping the motion of the heliostat.

If this is not the case, the position of the mirror I J must be corrected with extreme care by shifting the corner-pieces of wood, which are made expressly for this end. This must be done without jerks or jolts, which might derange the apparatus (this is why it is necessary first to fix its foot to the ground), and without stopping the motion of the heliostat. When at last this adjustment is made, put on the flap C D E B.

Management of the Apparatus.—The apparatus is now ready for use. And to use it, it is sufficient at any hour of the day, and on any day in the year whatever, to direct the sun's rays into the apparatus until the image of the sun is formed at the centre of the objective exactly as we have described at p. 8. As to the management of the parts constituting the optical apparatus, it is in everything similar to that of the horizontal apparatus, a description of which we have given at p. 238, and to this the reader must refer. The negative to be enlarged is placed at V in the cone of solar rays; the objective X serves for focussing; and the green glass Y serves for a shutter. Green glasses slide in the grooves K L, P O, &c.

Site of the Apparatus.—The shed which has to protect the apparatus may be made of either wood or masonry. Figs. 1 and 2, in pl. V., give a very accurate representation of it, one-twentieth of the actual size.

The following is its description:—

A C D B a wooden building of which the length, A C, is 5 *mètres*, the breadth at A B, 1¼ mètre, and at C D, 3 to 3½

mètres, the height, O D, 2½ mètres, and the height, O Z, of the roof; 1 mètre—the sides C D, A B being placed exactly in the line of the meridian,* and the side A C at right angles to them. The opening, *a b c d*, which gives passage to the heliostat, G L, has for its dimensions:—

$$ab = 2 \text{ mètres.}$$
$$bc = 1\tfrac{1}{2} \text{ mètre.}$$

This opening is closed by lateral shutters, H I, K J, moving on hinges, and a wooden flap, P, lined with zinc, the play of which is analogous to that represented in pl. IV., fig. 5.

E F is a straight line parallel to A C, which represents the axis of the optical apparatus, G. On this axis is the proof-frame, M N, the construction of which exactly corresponds with the drawing in fig. 6, pl. II., save that the centre of figure of this frame must be kept at the height, from the ground, of the enlarging objective of the apparatus.

The side B D should make an angle of at least 15 degrees with the sides A B, D C; for if this side were parallel to the opposite side, A C, of the shed, the image projected by the apparatus, L, would fall on this side. If, however, it is wished to form the part A B C D rectangular, the sides C D, A B, instead of being in the plane of the meridian, will then have to make with it an angle of some degrees. The apparatus will then be placed as represented in fig. 3.†

In all cases the aperture *a b c d* is closed by moveable curtains which envelope the cubical oaken box and the stand of the apparatus, and which ought to open readily, so that the moment the sun's rays from the heliostat are sent into the optical apparatus they can be observed by the person who directs the heliostat.

* On this point see what we have said at p. 236.

† In this case, the wall C B will now run in the direction of the shadow of the plumb-line at one o'clock in the afternoon. The dimensions of this room will be—B C = 3 mètres; A B = 4 mètres; the opening D E, &c., the same as that in figs. 1 and 2.

CHAPTER XII.

THE PARALLEL SOLAR LIGHT APPARATUS OF M. BERTSCH.*

M. Bertsch finds in Woodward's apparatus the defects which we have pointed out, and, to avoid them, he has constructed a small apparatus in which the condenser is suppressed, the negative being traversed by the direct rays of the sun. Fig. 87 represents the apparatus. The mirror, B, receives two

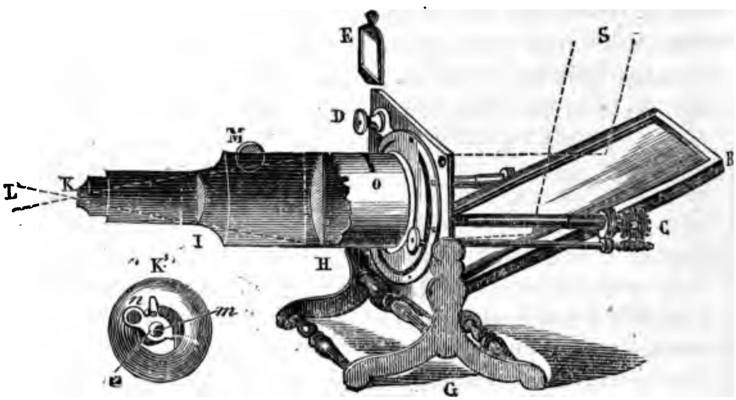


Fig. 87.

movements by means of a milled head D and a screw C, so as to bring the sun's rays S into the axis of the instrument. This moveable mirror is fixed in the shutter of a well-darkened

* A minute comparison has been made by the author of this work between the small-sized apparatus of Woodward (the condenser of which is no more than four inches in diameter) and M. Bertsch's apparatus, with the object of convincing himself whether in reality parallel light was to be preferred to convergent light for illuminating the negative to be enlarged. This comparison has made it evident that if the enlarging lens of *Woodward's* apparatus is constructed on the principles we have stated in speak-

room. The negative, which cannot be more than eight centimètres in the side, is fastened in a frame E, and introduced through a slit, O. The two achromatic lenses H and I, capable of being approached to or drawn back from the negative by means of the rack M, form the image on a screen

ing of this objective, no difference in the results can be perceived in the enlarged images furnished by the two apparatus.

M. Bertsch's apparatus, compared—and always with extrème care and in a great nnmber of experiments--with the dyalitic apparatus, of which the diameter of the condenser was not less than twenty inches, has not given better results, but the contrary, the considerable time required by this apparatus (that of M. Bertsch) for printing the proof tending to bring a certain haziness into the image in consequence of the inevitable motions of the ground, and the parts which support the apparatus. But in making these experiments, as soon as the optical image had made a slight impression on the photographic surfaces sufficient for judging of the sharpness of the image, they were arrested; and we were thus able to convince ourselves that the convergent light, properly employed, gives as good results as parallel light, besides possessing the advantage of an infinitely greater intensity.

This intensity, which M. Bertsch endeavours to dispute (Bareswill et Davanne, *Chimie Photographique*) by asserting that the thickness of the condensers absorbs a very large quantity of the incident light, thus taking from large condensers the advantage which their surface would lead us to expect, is such that M. Bertsch's apparatus requires forty times more time to print a proof of a negative than Woodward's apparatus, of which the condenser is nineteen inches across. The truth is that the intensity of the light given by the condensers is approximatively proportional to the squares of their diameters, which the law of absorption, stated at page 7, sufficiently explains.

The little intensity given by M. Bertsch's apparatus has caused this writer to print from the negative to be enlarged a small positive by transparency, and then to enlarge this to a negative from which positive proofs can then be taken in the pressure-frame. We shall presently speak of this method, which is hardly practicable, and which, above all, gives proofs infinitely less sharp than the method of direct enlargement of the negative on to the positive on paper.

Upon the whole, the apparatus (M. Bertsch's) gives proofs of great sharpness, most undoubtedly; but, according to us, this is due, not to the parallelism of the solar rays which illuminate the negative, but to the absence of all aberration in its illumination, the injurious effects of which aberration we have pointed out when speaking of the theory of Woodward's apparatus.

at a suitable distance. A diaphragm, K, which is at the end of the instrument, and placed at the principal focus of the objective H I, cuts off the diffused light.

This diaphragm, K, represented separately at K', carries a moveable plate pierced with two holes, *m* and *n*, the first open, the other closed by a yellow glass, which allows of the photogenic action of the apparatus being arrested at any desired moment.

The apparatus of M. Bertsch would be better, in a mechanical point of view, if the adjustible mirror were separated from the optical apparatus; for the wind, or a movement of the hand, causes the mirror to vibrate, and consequently also the optical apparatus, and often in this way destroys the sharpness of the enlarged image.

CHAPTER XIII.

INDIRECT ENLARGEMENT BY THE SUN OR BY DIFFUSED LIGHT.

Inferiority of this method over the direct method.— As we have just said, many persons, arguing from the frequent absence of the sun in northern climates, and the necessity under which the photographer by profession often finds himself of having to employ old negatives the intensity of which is too great for them to be enlarged by the solar camera, prefer to reproduce this negative as a positive by transparency, the intensity of which they regulate at pleasure, and which they next enlarge to a negative, from which they then print off as many positives on paper as they desire.

Evidently much of the sharpness of the original negative is

lost, for if the positive is taken from it by contact with dry collodion or at a distance by means of the camera, sharpness is at once lost by this operation (but less so in working at a distance by means of the camera than by contact). Secondly, in the act of enlarging this positive into a large negative, sharpness is further lost, particularly if diffused light is employed —(see p. 187, lines 22, *et seq.*) To this we may add, that in the enlarged negative the spots and defects of the original negative, of the positive, and lastly of this negative itself, are united. It is therefore very difficult to obtain with this method enlarged positive proofs which have not to be extensively touched up.

However, this method can be employed in winter when the absence of the sun renders it indispensable. It is carried out in two ways, either by means of the enlarging apparatus itself, which affords the most convenient disposition for this purpose, or by means of a camera and a good ordinary objective.

Conversion of the original Negative into a Positive by transparency.—The adjustible mirror of the apparatus, and the apparatus itself, being disposed in the way we have described, the mirror is so placed that it reflects the *diffused* light coming from the zenith on to the negative, which is put in the ordinary manner into the negative holder. If there is sun, the sun-light is directed into the apparatus, placing between the condenser and the negative to be enlarged and ten centimètres from the latter, a finely-ground glass or a sheet of oiled paper. *The objective is to be reversed*—that is, the lens of least diameter must face the negative to be enlarged. Moreover, the smallest diaphragm accompanying it must be put on. Lastly, apply to the objective the circular aperture of a small quarter-plate camera, and reproduce from the negative to be enlarged a small positive by transparency which should be at the most of the size of eight centimètres by six, whatever the dimension of the original negative (which we suppose, however, larger than eight cent. by six).

For the rest, this positive should present all the characters of a negative intended for enlarging, that is, intensity and an absence of fogging.

The enlarging apparatus, however, can just as well be dispensed with, and the original negative placed against a window and be reproduced of *carte-de-visite* size by means of a good ordinary objective (the triplet suits best) and a camera; but in general the employment of the enlarging apparatus is more convenient, because the mirror permits of the light of the sky upon which it is projected being reflected on to the negative.

The method which consists in applying a dry collodion plate over the negative in an ordinary pressure-frame, and obtaining thus, after its development, a positive by transparency, is not at all so good as the preceding, inasmuch as the surfaces are liable to rub and not to come completely together on account of want of flatness; and lastly, because we are not able to give to the positive the dimension the most advantageous, which is that of the *carte de visite.*

Enlargement of the Positive by means of the enlarging apparatus.—Place it as you would do a negative in the enlarging apparatus, employing the magnifying lens no longer in a reversed position as directed above, but in its normal position, represented in fig. 4, pl. II.

Make use either of diffused light or of sunlight; with the latter, in order to lessen the excessive power of the illumination, interpose between the condenser and the mirror two, three, or even four deep-blue glasses, which will absorb a great part of it. Never interpose, as some persons advise, a ground-glass between the condenser and the positive to be enlarged. But if you do so, you must furnish the enlarging lens with the smallest of its diaphragms; whereas with sunlight transmitted through blue glasses you can employ larger diaphragms, and even the largest of all, without affecting the sharpness of the enlarged image.*

* P. 187 will make this intelligible to the reader.

The image of the positive to be enlarged should be thrown on the sensitised collodion surface either dry or moist. Waxed paper may also be used, but the time of the operation is much longer, and is too long when we are working without sun.

It is well, particularly when we are working with moist collodion, to attach a conical bellows to the enlarging lens and the holder of the glass bearing the collodion-surface, in order to preserve this from all light but that proceeding from the positive to be enlarged.

The focussing of the enlarged image is effected with much greater sharpness by sunlight than by diffused light; and the rapidity in printing is necessarily much greater. Most frequently, after having interposed the blue glasses we have spoken of, the time of exposure is, so to speak, instantaneous, while with diffused light it is always several minutes. We here suppose the employment of moist collodion; dry collodion, and waxed paper especially, requiring a much longer time. The enlarged negative obtained then serves for taking positives on paper by the ordinary method.

Enlargement of the Positive by the Camera Obscura.—Place the positive to be enlarged quite vertically up against a fully exposed window, and if the sun comes on this window place the positive over a ground-glass, leaving between the two glasses a space of one centimètre, in order that the grain of the ground-glass may not come out in the enlarged negative.

It is well, in order to prevent reflections of light in the camera, to place round the positive a strip of black paper twenty centimètres wide, or better, to place the positive in a wooden frame made for the purpose, the edges of which are joined to those of the camera by a piece of some black material, which keeps out all light that has not traversed the said negative.

Now put a triplet of fifteen or twenty centimètres' focal length on a camera with bellows-movement, of a size adapted to that of the enlarged negative you desire to obtain, and of a suitable length; and so arrange that the centre of the

positive to be enlarged may be situated in the optical axis of the triplet and its surface quite perpendicular to this axis. *Reverse the triplet in its mounting*, so that the largest lens faces the positive to be enlarged, and then focus by drawing back the ground-glass from the objective, at the same time that you so regulate the distance of the latter from the positive as to get its enlarged image sharp over a surface of given size.

The rest of the operations are performed in the usual way of using moist collodion.

This method, which is a very old one, has given very good results in the hands of M. Verneuil, the French photographer, who in the course of the year 1865 laid before a meeting of the *Société Française de Photographie* very fine enlarged proofs obtained by this process.

CHAPTER XIV.

APPLICATION OF ARTIFICIAL LIGHT TO ENLARGING APPARATUS.

Necessity of a Light of very great brilliancy within a very small surface.—If a great *quantity* of light were sufficient for illuminating the negative in the enlarging apparatus, this could easily be obtained from flames of very large surface. But the cone of rays emergent from the condenser of the optical apparatus must have a very small summit for its surface, because the enlarging lens situated at the summit of this cone has itself only a small surface. Further, if the summit of the cone of light strikes the edges of the mounting of the enlarging lens, there is, as we have explained

on p. 177, *et seq.*, a production of diffraction-blurs in the enlarged image. A friend of ours, M. A. Neyt, of Ghent, made on this point some very conclusive experiments, using both the electric light and the Drummond light as a source of light in a magnificent solar microscope by Hartnack, with convergent light or with parallel light (so extolled by M. Bertsch); and he found that whenever the luminous spot had too large a surface, and that consequently its image fell on the edges of the enlarging objectives, diffraction-blurs were produced in the magnified image, by the employment of parallel light as well as by that of convergent light, even when using condensers which were achromatic, such as that of the microscope which he employed.

Flames therefore which possess considerable photogenic power, like those of cyanogen, Way's electric mercury-lamp, white Bengal lights of arsenic, antimony, nitrate of magnesia, petroleum lamps, and even magnesium-wire lamps, do not serve for photographic enlargement.

The flames of very small surface which are especially suitable are, the electric light produced between carbon-points, and the Drummond light, in which a compact cylinder of magnesia is substituted for the lime cylinder.

The electric light ought to be produced by fifty of Bunsen's elements, large size, and the electric lamp be of very perfect make, so as to keep the luminous point well in the axis of the optical apparatus. For if this point came to be displaced, not only would the enlarged image be to a very small extent displaced by the thickness of the lenses which form the enlarging objective, but diffraction-blurs might be produced; and these are two circumstances that would affect the sharpness of the magnified image.

The best forms of electric lamp are M. Serrin's and M. Léon Foucault's, particularly the latter, which can be procured at M. Dubosq's, philosophical-instrument maker, Paris, who, we believe, is entrusted by the inventor with the manufacture of this lamp.

Every one knows the Drummond light: a pointed lime cylinder, the extremity of which is made white hot by an inflamed jet of oxy-hydrogen gas, so as to give a spot of very intense light. If a cylinder of compact magnesia (obtained by calcination of nitrate of magnesia in covered crucibles) is substituted for the lime cylinder, the point of light, without being more brilliant to the eye, is much more photogenic—a result which is probably caused by the particles of magnesia giving to the flame the properties of that of burning magnesium itself.

Instead of compact magnesia, Prof. Carlevaris of Genoa makes use of light magnesia, and applies this light with success to one of our eight-inch enlarging apparatus. He assures me that he has thus made enlarged proofs one mètre square in less than one minute. Probably on moist iodised paper, and after development, in the way practised in Paris by M. Numablanc with the electric light, they could be taken in a much shorter time.

Lastly, there is one method, surpassing all the others, which consists in throwing oxy-hydrogen gas under a strong pressure (of at least one mètre of water) by means of a platinum blow-pipe, so as to obtain a jet four or five centimètres long upon the point of one of the small parallelopipeds of hard charcoal which are used in the electric lamp, moistened with chloride of magnesium. It is the most powerful of all lights in a photographic point of view, and the most economic. This luminous point, just as that of the electric lamp, should be maintained with care in the optical axis of the enlarging apparatus, in order to prevent the enlarged image being deficient in sharpness, as we have said above.

Disposition of the Optical Apparatus.—If a parabolic reflector were made use of to throw the light from the illuminating point upon the condenser of the apparatus, the image of the support of the point would be visible in the form of a shadow over the enlarged image.

In fact, stick a wafer, *a* (fig. 14, pl. I.), on the condenser, L, of an enlarging apparatus or of a solar microscope, and

the image of the wafer—invisible at the focus, *f*, of the condenser—will become very *distinctly* visible in front of, *b*, or behind, *c*, this focus. Now the support of the luminous point cutting off a portion of the parallel rays reflected by the parabolic mirror, produces here the same effect of an opaque screen as the wafer.

The following is an arrangement which, if it collects less light upon the condenser than the parabolic reflector, is exempt from the defect which we have just recognised in it.

Let A B C (fig. 13, pl. I.) be a spherical glass mirror with parallel surfaces, of which one, A B C, is silvered. Let B I be the axis of the mirror, and D its centre of curvature, where we place the luminous point D. Let E G be a plano-convex *flint*-glass lens on the same axis, I B, of which the diameter is the same as that of the mirror, A C, and the focal length, F D, exactly equal to D B, the radius of the mirror A C.

Every ray of light, D A, emanating from the luminous point, D, and striking the mirror, A C, returns along A D, and, continuing its way, strikes the lens, E G, from which it emerges parallel to the axis. In the same way, every ray, D E, which emanates from the luminous point, D, and which strikes the lens, emerges parallel to the former and to the axis. In this way, the support, D K, is not visible at all on the enlarged image.

The following are the numerical data of this arrangement, in which we make use of flint-glass of which the index is 1·6 instead of crown-glass of 1·5 index, in order to avoid too great a thickness of the lens E G, which should have a focal length as short as possible, and equal to the radius, B D, of the mirror, A B C. R is the radius of the mirror A C, μ its thickness, D its diameter, and R′ the radius of curvature of the lens, E G (the other face being plane).

D	R	μ	R′
216 millimètres	25 centimètres	4 millimètres	15 centimètres.
380 "	45 "	6 "	27 "
513 "	60 "	8 "	36 "

These data are sufficient for any optician to construct similar apparatus at the desire of the reader. They accord, besides, with the sizes of condensers most in use, which are 19 inches (513 millimètres), 14 inches (380 millimètres), and 8 inches (216 millimètres).

This apparatus is set up in the axis itself of the enlarging apparatus, the optical part of which, L M, and the management remain in every respect the same as in our description of these apparatus. The diameter of the lens, E G, ought to be equal to that of the condenser, L, which moreover is placed as near as possible to this lens.

Choice of the Photographic Process.—The luminosity of the artificial light being infinitely less intense than that of the sun, the application of this artificial light to enlarging by the ordinary processes with albumenised or chloride-of-silver paper cannot be thought of; for it would then be necessary to continue the printing of the image for whole days. Paper prepared with nitro-glucose,* a process which we have described in the *Bulletin de la Société Française de Photographie*, for 1865, p. 143, requires about an hour's exposure for a size of enlarged image fifty centimètres by sixty. Paper prepared with iodide of potassium and arrowroot, sensitised in an aceto-nitrate of silver bath, and employed immediately, and consequently moist, gives by development proofs in ten or twelve minutes, but much less fine in tone than those obtained with nitro-glucose paper.

M. Vilette † obtains very fine positive proofs from a small negative by projecting the enlarged image on a surface of collodion, which he then transfers to paper. He makes use of artificial light (the Drummond light), and an optical apparatus similar to that we have described above and constructed by M. Duboscq of Paris. The time of exposure is one minute for an enlarged proof sixty centimètres by fifty.

* It can be obtained in Paris, at Romain Talbot's, 50 Rue d'Enghien.

† *Bull. Soc. Fr. de Phot.* for 1865, p. 149.

Unfortunately the process of transferring the collodion film on to paper requires very great practice. But the proofs produced by M. Vilette, which we have seen, are of a beautiful black tone, imitating that of an engraving, and of necessity very fine, because the optical apparatus is very perfect.

We have only to add, in conclusion, that the application of artificial light to enlargements is particularly advantageous for enlarging small positives by transparency into large negatives in the way we have described in the preceding chapter.

THE END.

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